TESTS OF WATTHOUR METER

BY
I. GOLDBERG
S. SACKHEIM

ARMOUR INSTITUTE OF TECHNOLOGY
1911

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Complete tests of the Willis
"Straight Line" Watthour

COMPLETE TESTS
of the
WILLIS "STRAIGHT LINE" WATTHOUR METER
and the
COLUMBIA SHUNTED ASTATIC WATTHOUR METER

A THESIS

PRESENTED BY

I. GOLDBERG.
S. SACKHEIM.

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

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Prof. of Elec. Eng.

L. C. Monin,
Dean of Cultural Studies

H. M. Raymond
Dean of Eng. Studies

537.7
G57

The object of this thesis is to make a complete investigation of the accuracy of two new types of integrating watthour meters, namely:

1. The Willis "Straight Line" Meter #3551.
2. The Columbia Shunted Astatic Meter #18600.

22760

In the performance of the various tests the following apparatus was used:

Weston D.C. Voltmeter	#4405	0 - 150 volts.
Weston D.C. Ammeter	#227	0 - 10 amperes.
Weston D.C. Ammeter	#7527	0 - 150 amperes.
Weston A.C. Voltmeter	#2911	0 - 120 volts.
Weston Wattmeter	#433	0 - 1500 watts.

General Electric A.C. Ammeter #2024274- 0-5, 0-10 amp.
Wagner Electric 60 Cycle Alternator #182.
General Electric 25 Cycle Rotary Converter #17721.
Holzer Cabot 60 Cycle Alternator #16881.
Potential Rheostats.
Current Rheostats.
Choke Coil.
Lamp Rack.
Condensers.
Variable inductance.
Frequency meter.
Revolution counter.
Thermometers.
Storage Cell.
Auto-transformer. Shunts.
Keys. Stop-Watch.
High resistance coil for producing magnetic field.
Box with heaters for making temperature tests.

Theory of The Motor Type of Wattmeters.

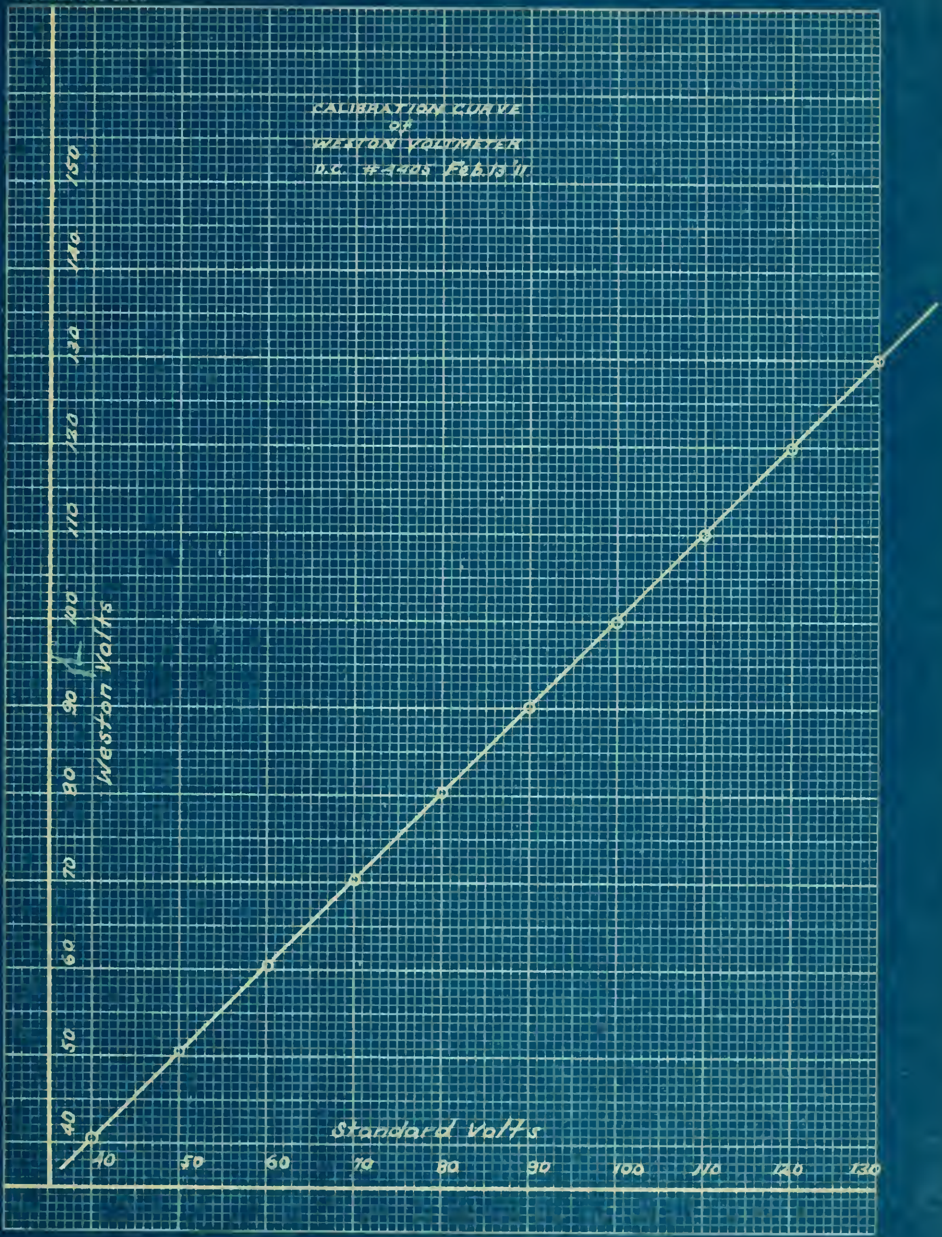
Practically all the meters, which are suitable for both alternating and direct currents, are of the motor type, having a wound armature with a commutator and brushes connected thru a high and practically non-inductive resistance across the supply mains, the armature being in a field produced by the main current passing thru a fixed coil or coils. Two fields are therefore produced; one, by the armature proportional to the current thru it, and the other proportional to the current in the field coils, which is the current supplied to the load.

The brushes are placed on the commutator at such an angle that the armature field is approximately at right angles to the main-current field, with the result that a torque is produced tending to bring the coils in the same plane.The Commutator causing the fields to be permanently at the same angle, the torque remains, and the armature rotates as long as both fields exist.A metal disc attached to the same spindle as the armature, rotating between the poles of a permanent magnet provides a retarding torque which is proportional to the watts delivered.

CALIBRATION OF INSTRUMENTS

Calibration of Weston D.C. Voltmeter #4405.

Standard Volts.	Weston Volts.
30	30.7
40	40.6
50	50.6
60	60.5
70	70.3
80	80.3
90	90.2
100	100.1
110	100.0
120	119.9
130	129.9
140	140.0
150	150.0

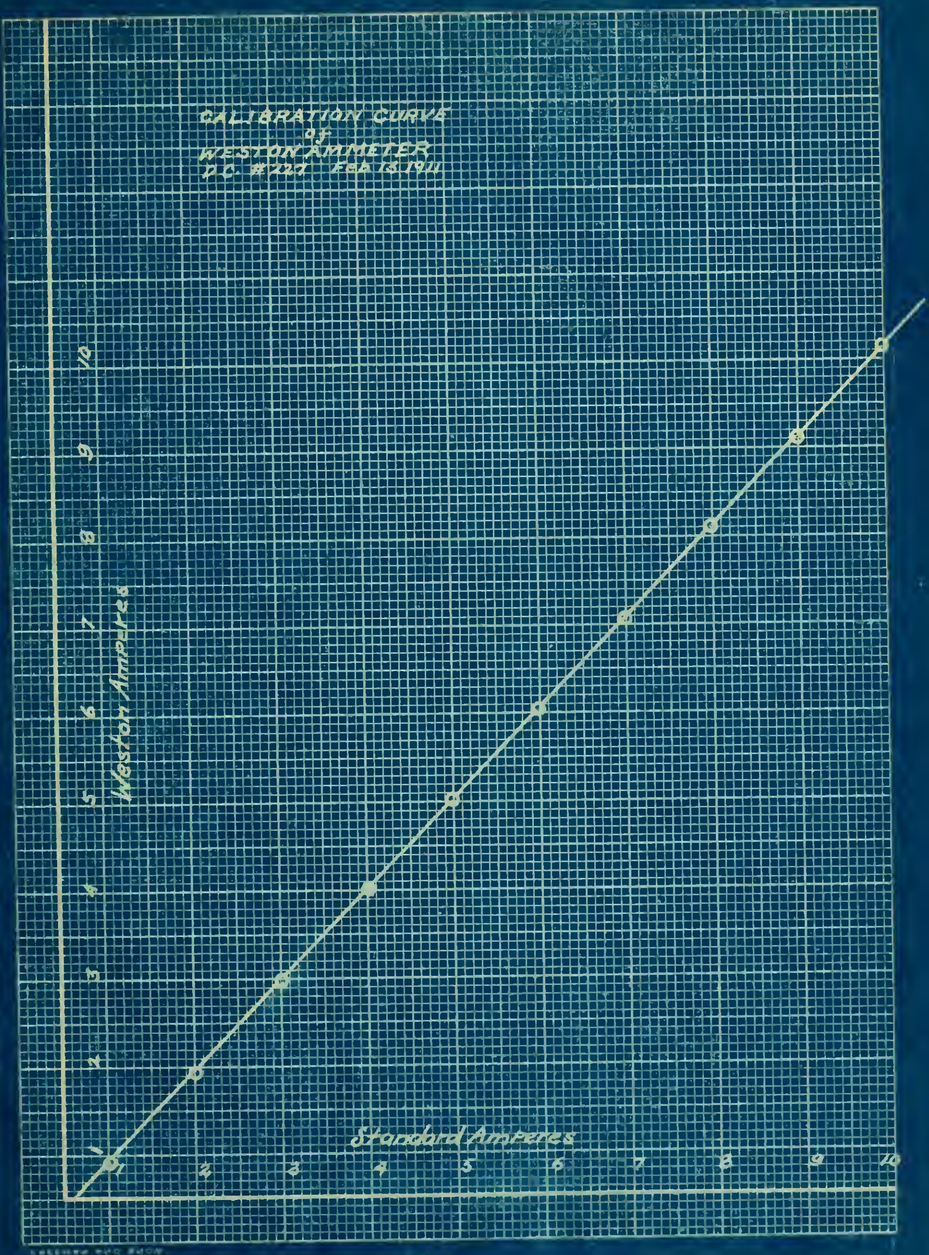

CALIBRATION CURVE
OF
WESTON VOLTMETER
D.C. #4405 Feb.13 '11
Weston Volts
40
50
60
70
80
90
100
110
120
130
140
150
Standard Volts
40
50
60
70
80
90
100
110
120
130

Calibration of Weston D.C. Ammeter #227.

Standard Amperes	Weston Amperes.
1	.95
2	1.97
3	2.98
4	4.00
5	5.03
6	6.08
7	7.10
8	8.10
9	9.12
10	10.15

Calibration of Weston D.C. Ammeter #227.

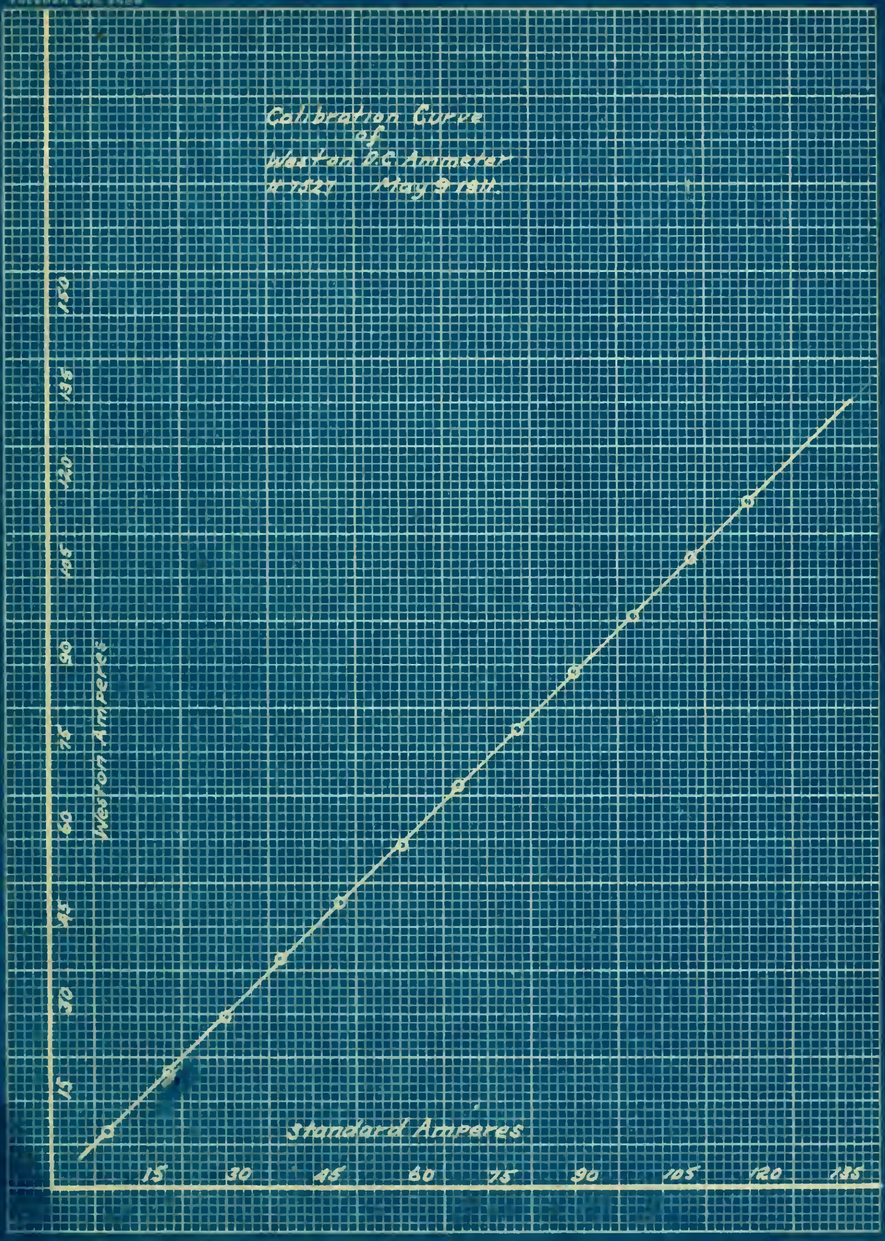
Standard Amperes	Weston Amperes.
1	.95
2	1.97
3	2.98
4	4.00
5	5.03
6	6.08
7	7.10
8	8.10
9	9.12
10	10.15


CALIBRATION CURVE
of
WESTON AMMETER
D.C. #227 FEB 15 1914
Weston Amperes
1
2
3
4
5
6
7
8
9
10
Standard Amperes
1
2
3
4
5
6
7
8
9
10

Calibration of Weston D.C. Ammeters # 7527.

Standard Amperes.	Weston Amperes.
10	10.0
20	19.8
30	29.7
40	39.3
50	49.0
60	58.9
70	68.7
80	78.6
90	88.4
100	98.1
110	1 07.8
120	117.6

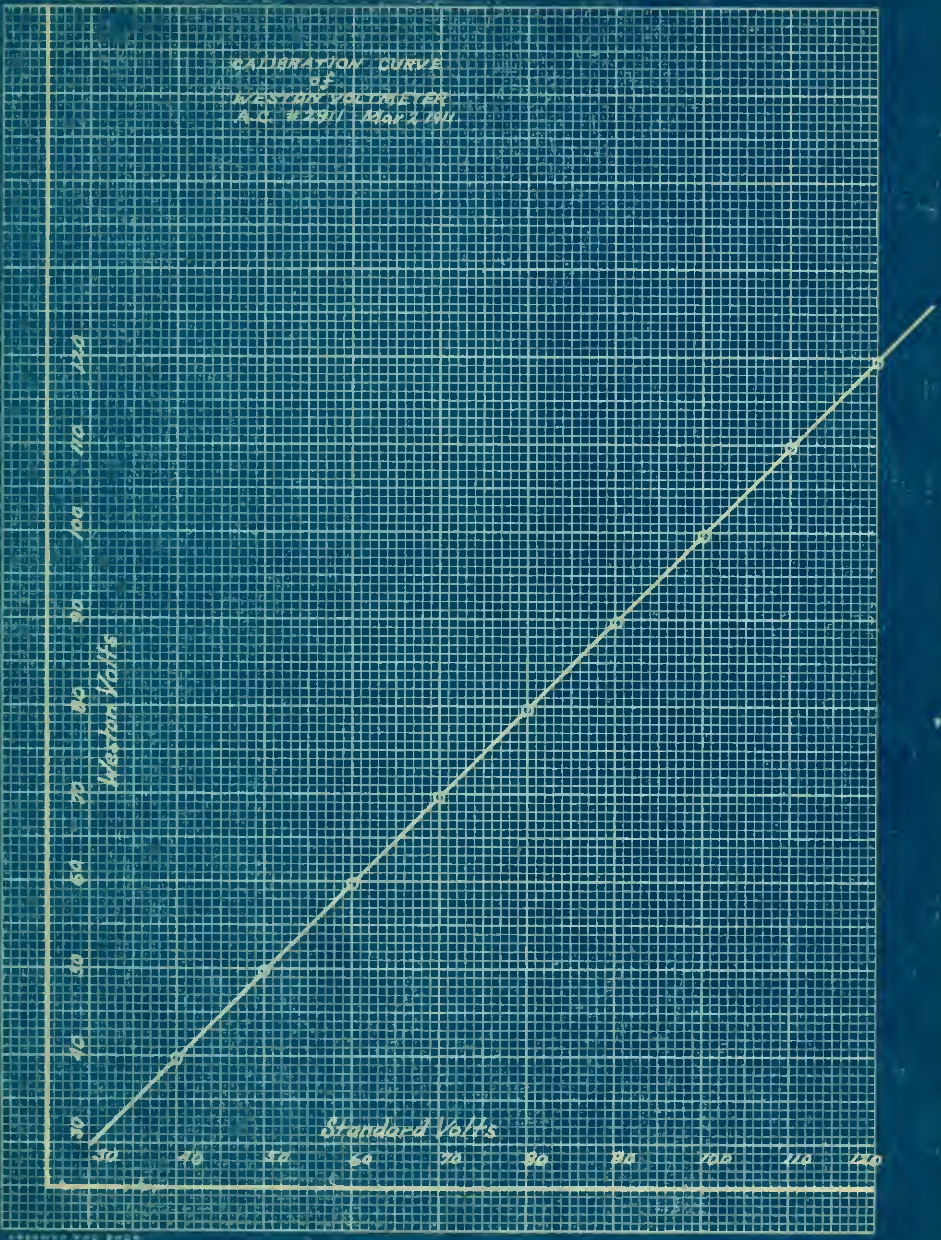
FREEMAN AND SNOW



Calibration Curve
of
Weston D.C. Ammeter
#7527 May 9 1911.

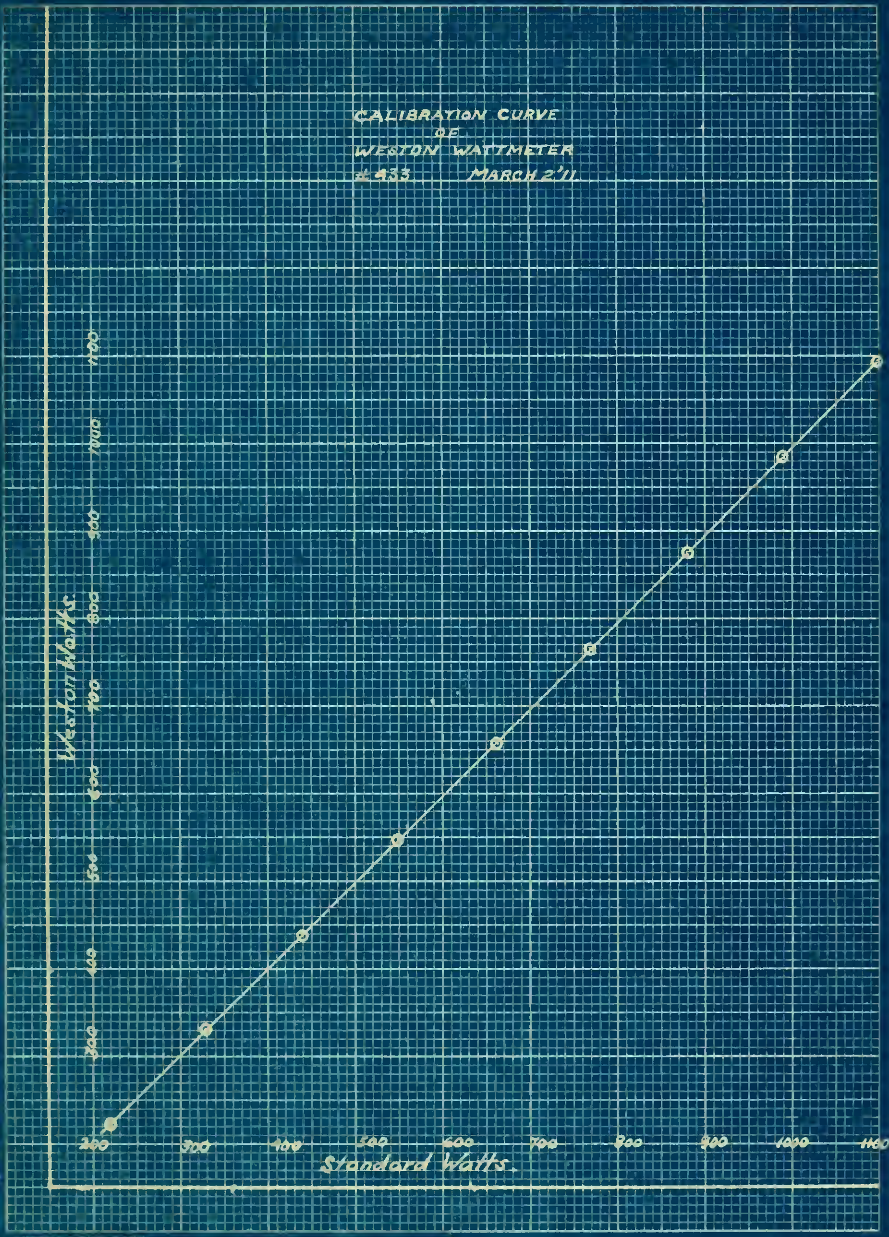
Calibration of Weston A.C. Voltmeter # 2911.

Standard Volts.	Weston Volts.
30	29.80
40	39.65
50	49.80
60	59.80
70	69.80
80	79.65
90	89.70
100	99.80
110	109.75
120	119.65


CALIBRATION CURVE
of
WESTON VOLTMETER
A.C. #2911 Mar 2 1911
Weston Volts
30
40
50
60
70
80
90
100
110
120
Standard Volts
30
40
50
60
70
80
90
100
110
120

Calibration of Weston Wattmeter # 433.

Standard Watts.	Weston Watts.
110	115
220	223
330	330
440	439
550	547
660	655
770	765
880	874
990	984
1100	1093


CALIBRATION CURVE
OF
WESTON WATTMETER
#433 MARCH 2'11
Weston Watts.
300
400
500
600
700
800
900
1000
1100
Standard Watts.
200
300
400
500
600
700
800
900
1000
1100

The General Electric A.C. Ammeter # 202427 was not calibrated. It was a new instrument and upon being checked with another instrument of the same type, the two were found to give exact results.

THE WILLIS "STRAIGHT LINE" METER.

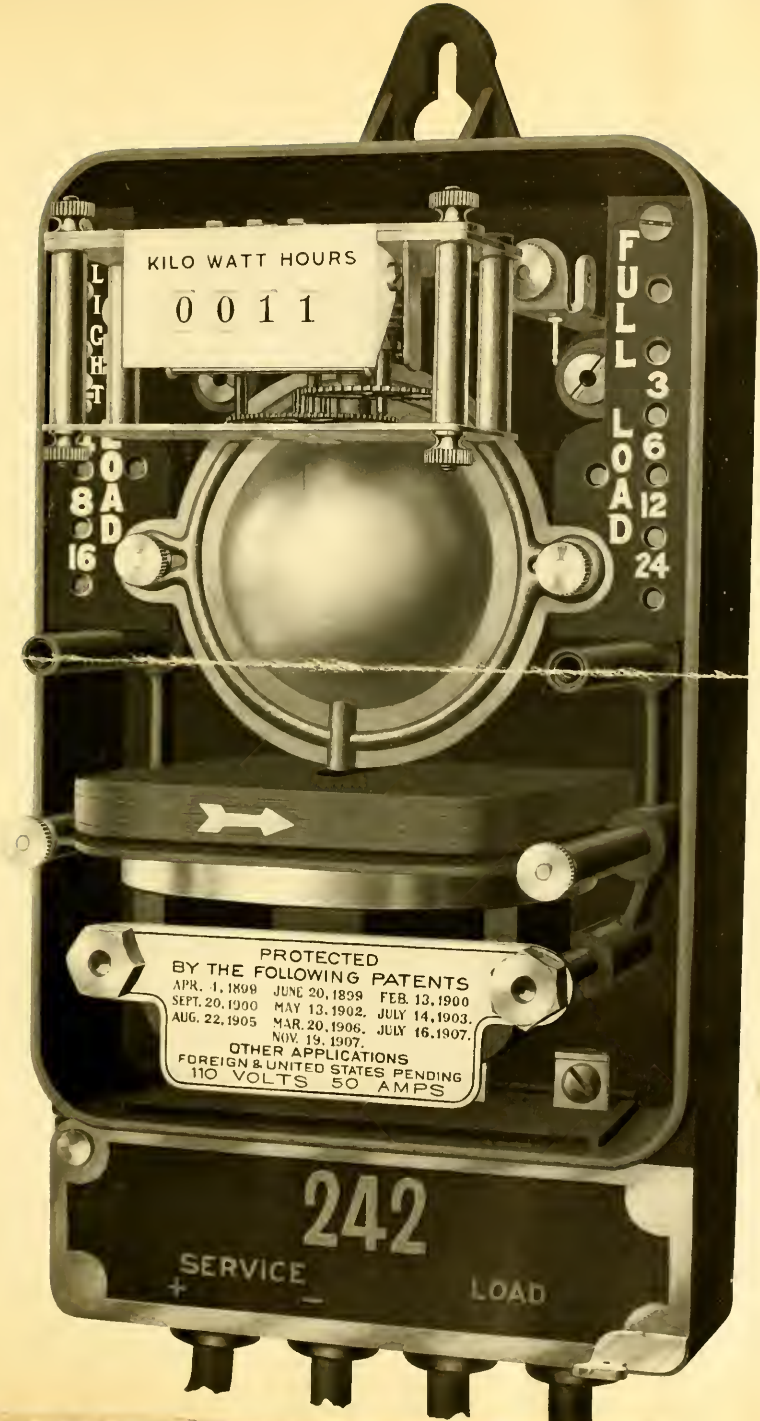
The Willis "Straight Line" meter, photographs of which are shown on the following pages, operates on either direct or alternating current without readjustment or recalibration. The meter measures 5 3/4" by 10 1/2" and is 5 3/8" deep. It is covered by a glass case which is held in place by two bolts fitted with rubber bushings which make the meter air-tight when assembled.

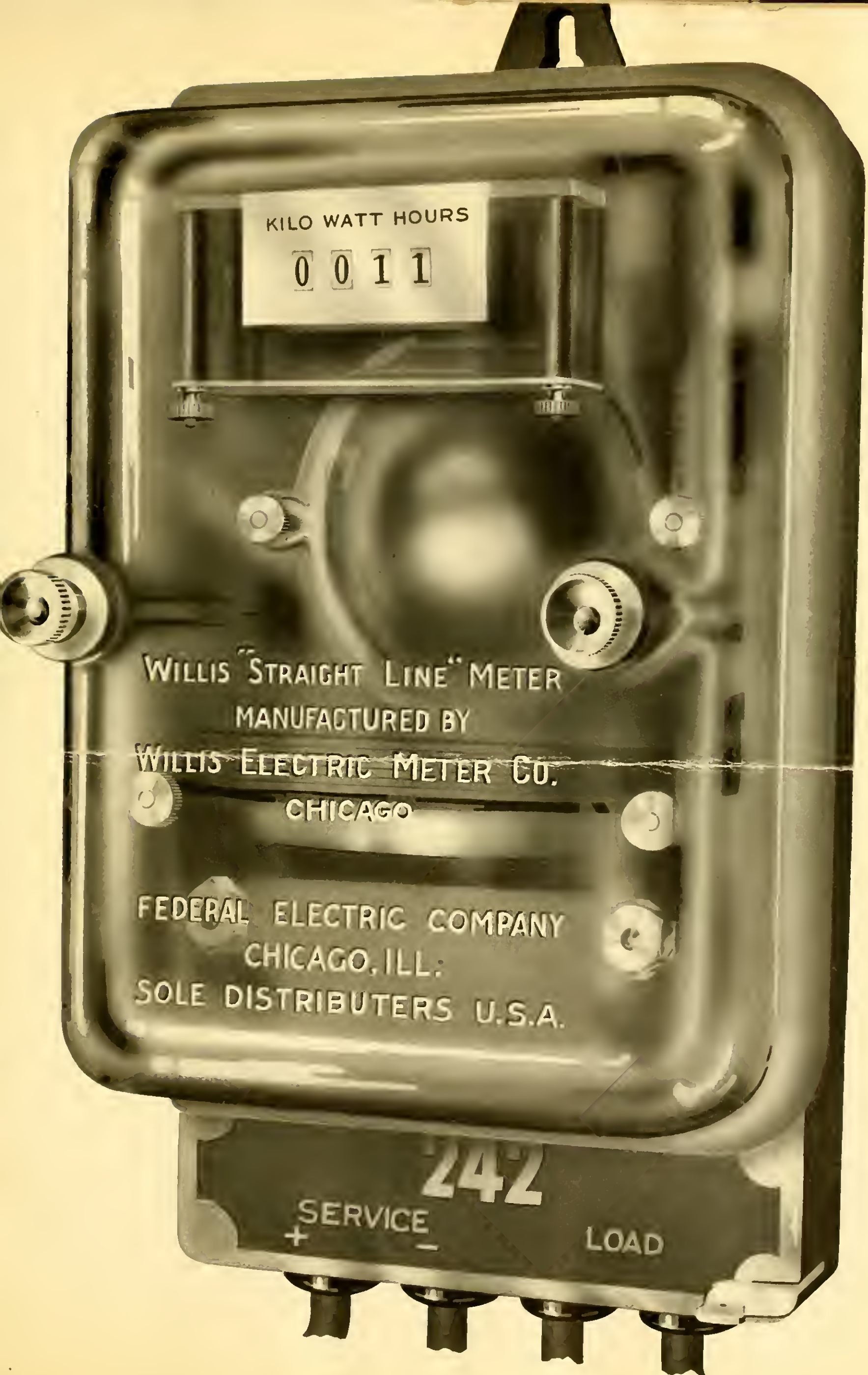
In place of the usual index dial this meter has an index showing a line of plain figures. All the working parts of the index are gold-plated to prevent corrosion.

The magnets at the bottom of the meter are not adjustable, thus making corrections by this means impossible. The adjustment is accomplished by means of plugs on the top sides of the meter which put resistance in the pressure circuit.

The core of the armature is made of cork thus insuring minimum weight for the rotating member. The armature is covered by a gold-plated hollow hemisphere secured by two knurled head nuts. To further eliminate friction the meter has ball bearings instead of the usual pivo

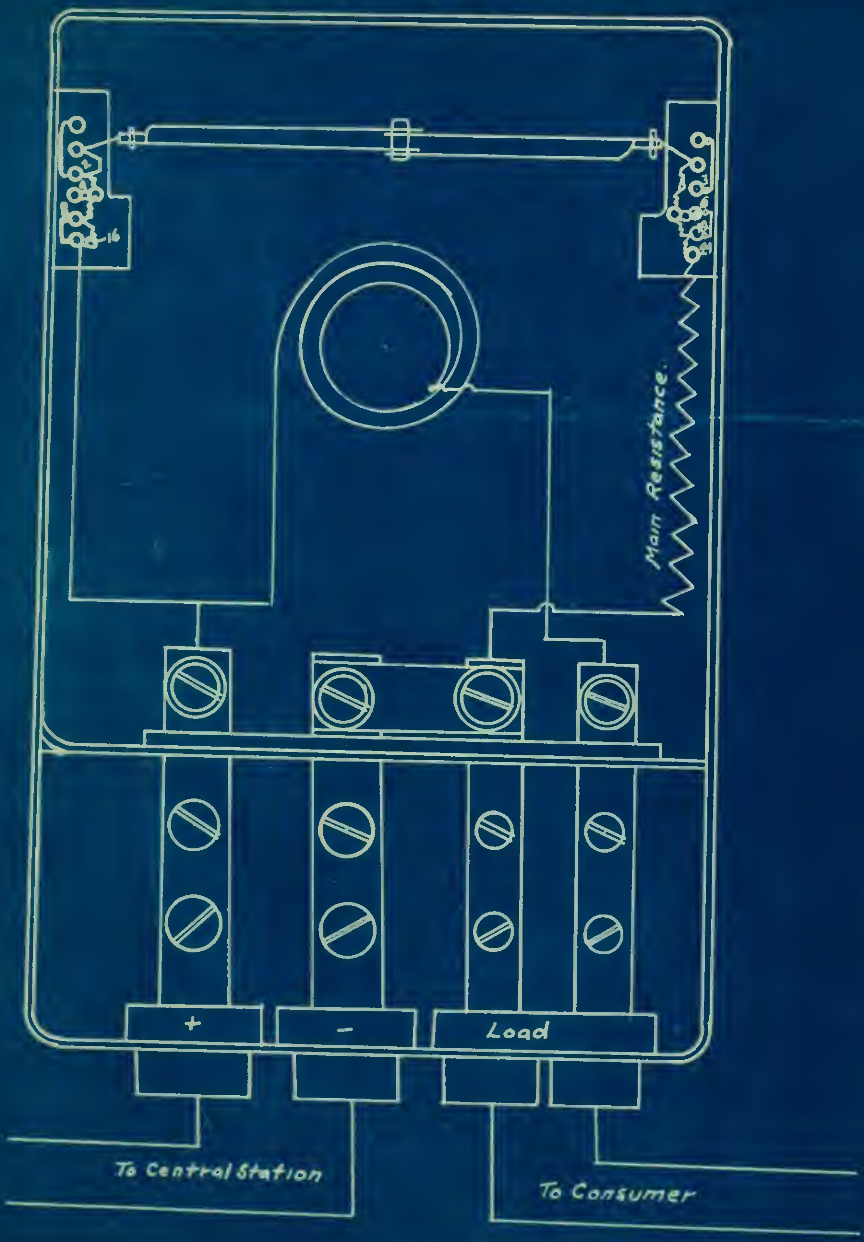
The meter is so constructed that it can be taken apart with very little trouble and any defective part can be easily replaced.


KILO WATT HOURS
0 0 1 1
LIGHT LOAD
8
16
FULL LOAD
3
6
12
24
PROTECTED
BY THE FOLLOWING PATENTS
APR. 4, 1899 JUNE 20, 1899 FEB. 13, 1900
SEPT. 20, 1900 MAY 13, 1902. JULY 14, 1903.
AUG. 22, 1905 MAR. 20, 1906. JULY 16, 1907.
NOV. 19, 1907.
OTHER APPLICATIONS
FOREIGN & UNITED STATES PENDING
110 VOLTS 50 AMPS
242
SERVICE
+
−
LOAD


KILO WATT HOURS
0 0 1 1
WILLIS "STRAIGHT LINE" METER
MANUFACTURED BY
WILLIS ELECTRIC METER CO.
CHICAGO
FEDERAL ELECTRIC COMPANY
CHICAGO, ILL.
SOLE DISTRIBUTERS U.S.A.
242
SERVICE
+
−
LOAD

FULL SIZE

Connections For 2 Wire Willis "Straight Line" Meter.



DIRECT CURRENT TESTS

In performing the direct current tests on the Willis "Straight Line" Meter # 3551, the instruments were connected up as shown in the scheme of connections on the following page. Current was obtained from a single storage cell and the supply of current was regulated by means of a carbon plate rheostat. The pressure was obtained from a storage battery situated in the north laboratory and the voltage was maintained constant by means of a variable potential rheostat.

Five direct current tests were made on this meter as follows:

1. Meter operated at 110 volts with load varying from 0 to 50% overload.

2. Meter operated at 120 volts with load varying from 0 to 50% overload.

3. Meter operated at 100 volts with load varying from 0 to 50% overload.

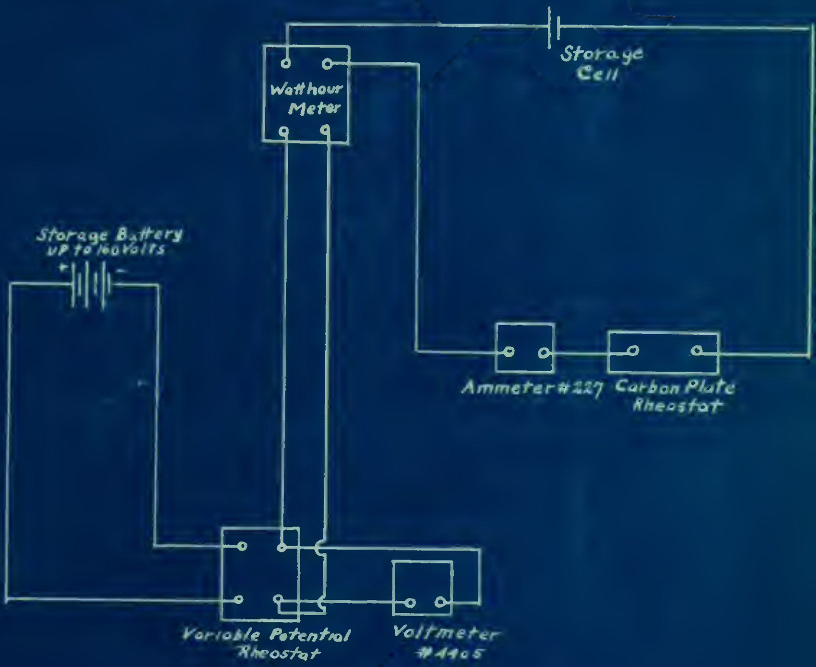
4. Meter operated at full load with e.m.f. varying from 50 volts to 130 volts.

5. Temperature test.

Each test consisted of a number of six minute runs. For each run the current, voltage, and number of revolutions of the disc, were recorded.

For test number five the meter was placed in a large air-tight box containg four electric heaters, which were used to vary the temperature of the meter. Runs were made for four variations in temperature.

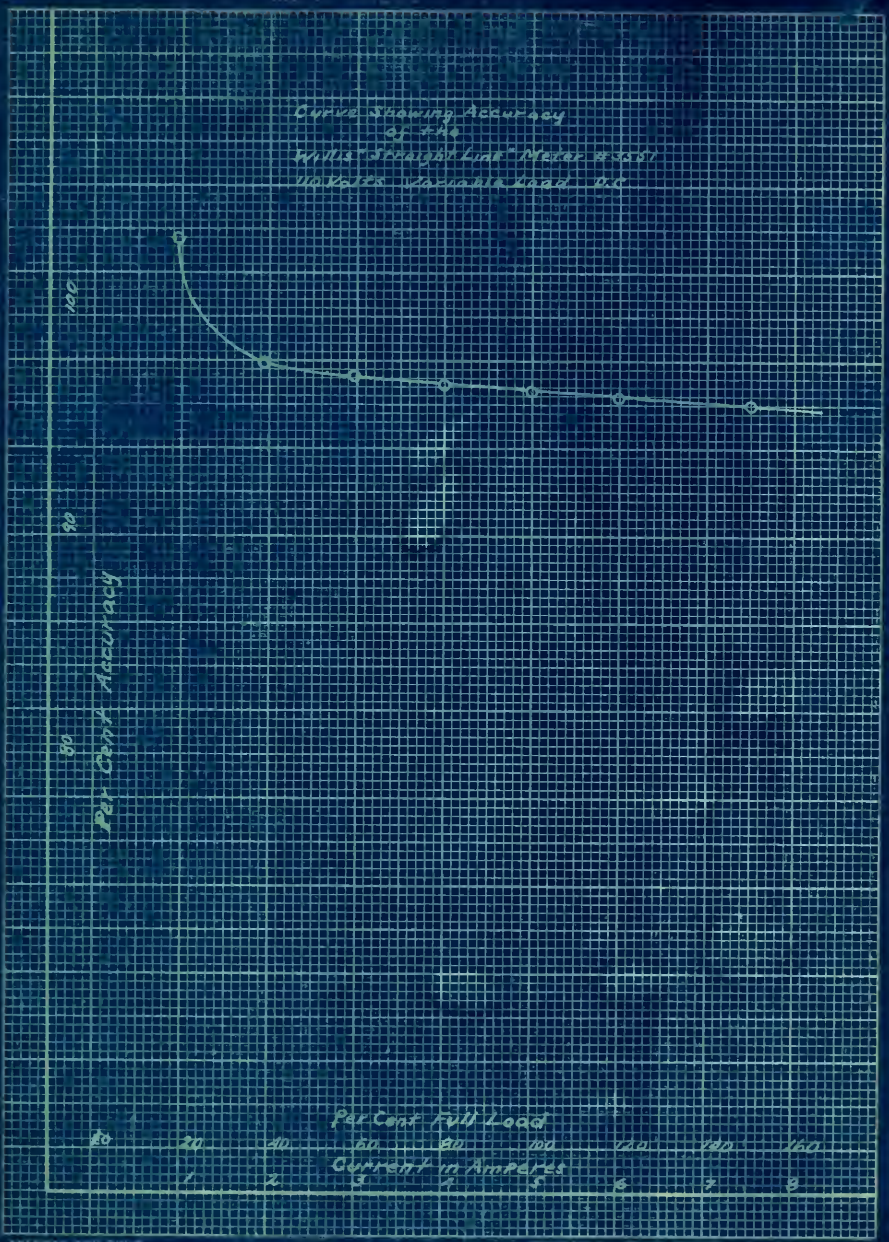
Scheme of Connections for D.C. Tests.



DATA AND CURVES
# of D.C. TESTS.

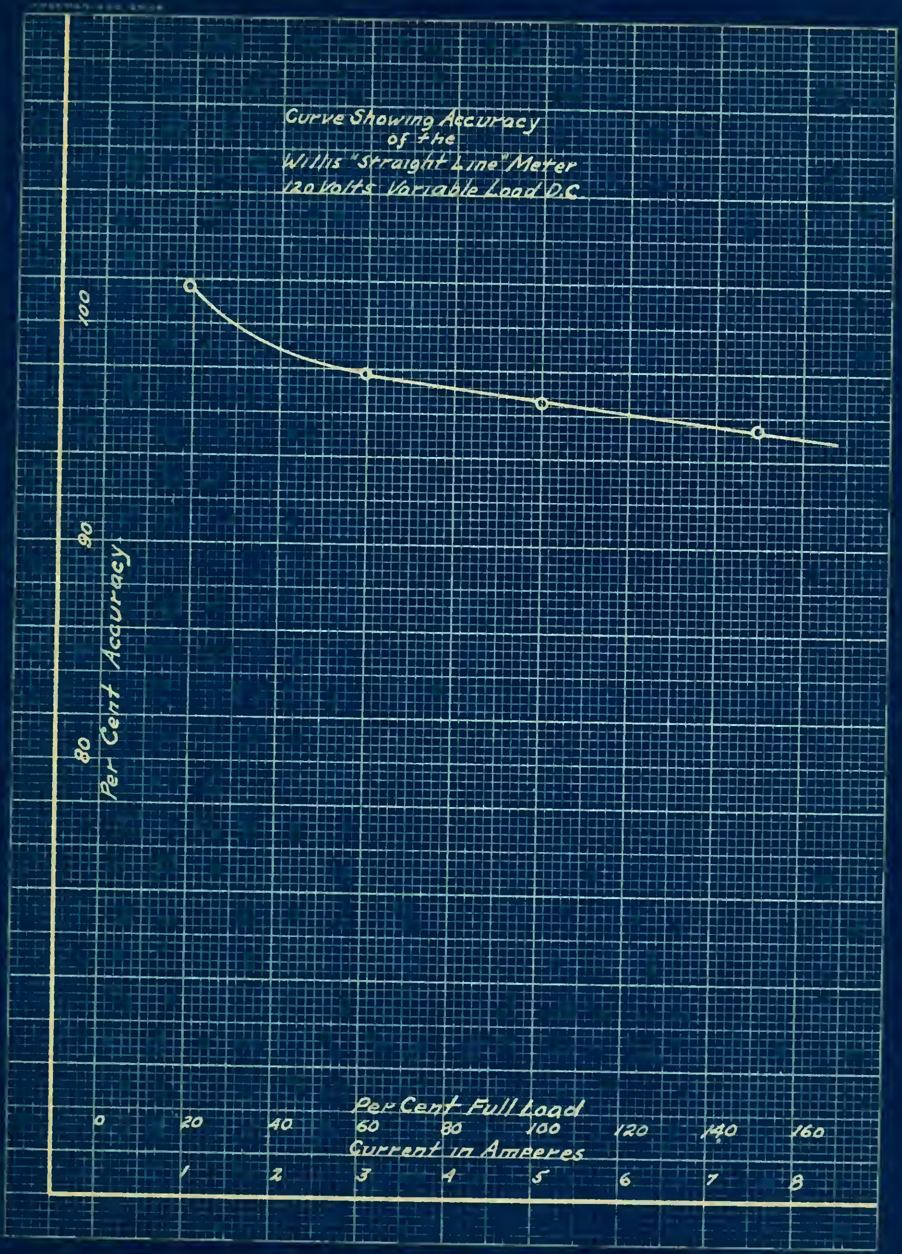
Data showing the effect of varying the load from 0 to 50% overload when the meter was operated at 110 volts.

Amperes.	Rev.	True W.H.	Meter W.H.	%Accuracy.
.94	128.5	10.34	10.71	103.60
1.95	252	21.45	21.00	97.90
2.97	381	32.65	31.81	97.32
4.00	511	44.00	42.60	96.87
5.03	642	55.35	53.60	96.65
6.08	773	66.90	64.44	96.36
7.60	960	83.60	80.21	95.95


Curve Showing Accuracy
of the
Willis "Straight Line" Meter #3551
110 Volts Variable Load D.C
Per Cent Accuracy
100
90
80
Per Cent Full Load
0
20
40
60
80
100
120
140
160
Current in Amperes
1
2
3
4
5
6
7
8

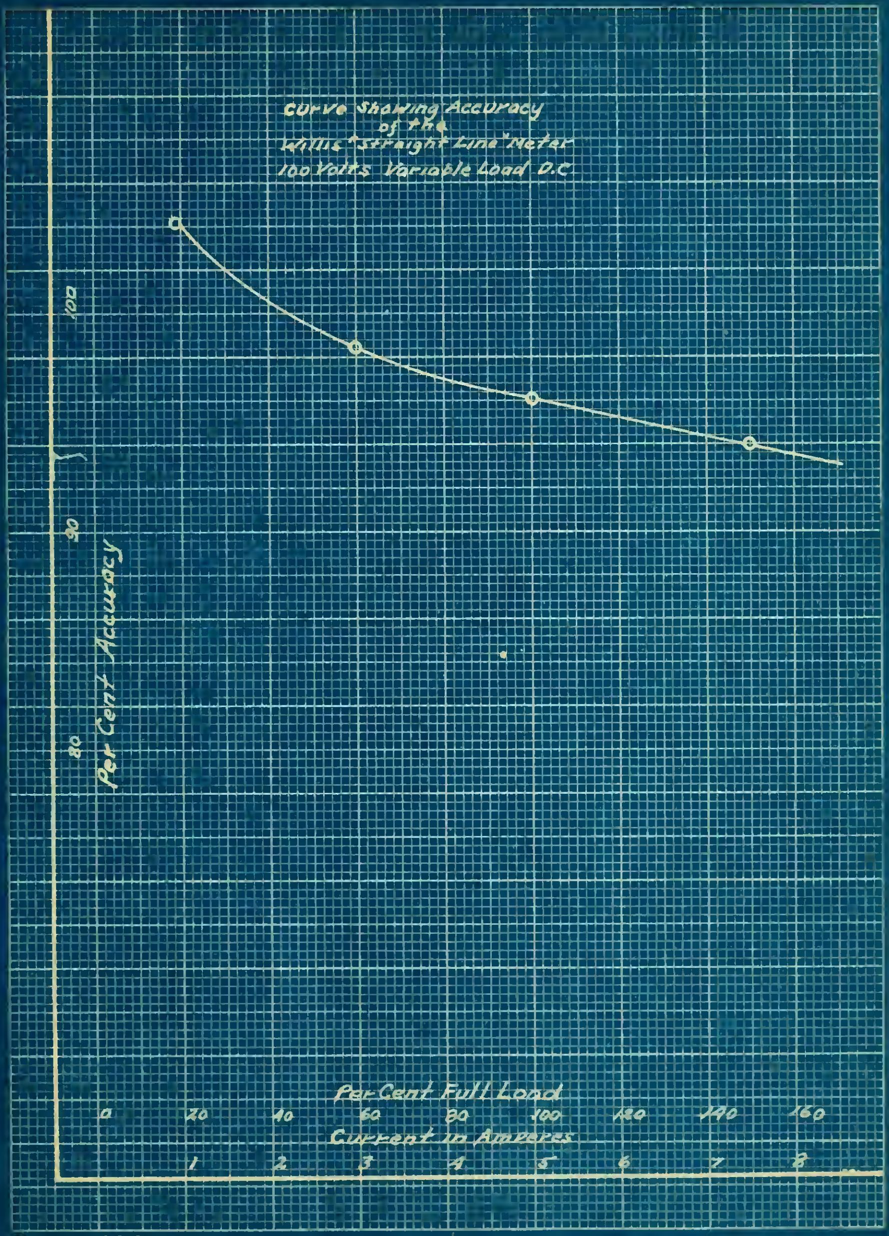
Data showing the effect of varying the load from 0 to 50% overload when the meter was operated at 120 volts.

Amperes.	Rev.	True W.H.	Meter W.H.	% Acurracy.
.94	138	11.27	11.67	101.70
2.97	418	35.61	34.80	97.80
5.03	698	60.43	58.15	96.51
7.60	1095	91.20	87.95	95.42


Curve Showing Accuracy
of the
Willis "Straight Line" Meter
120 Volts Variable Load D.C.
100
90
80
Per Cent Accuracy
Per Cent Full Load
0
20
40
60
80
100
120
140
160
Current in Amperes
1
2
3
4
5
6
7
8

Data showing the effect of varying the load from 0 to 50% overload when the meter was operated at 100 volts.

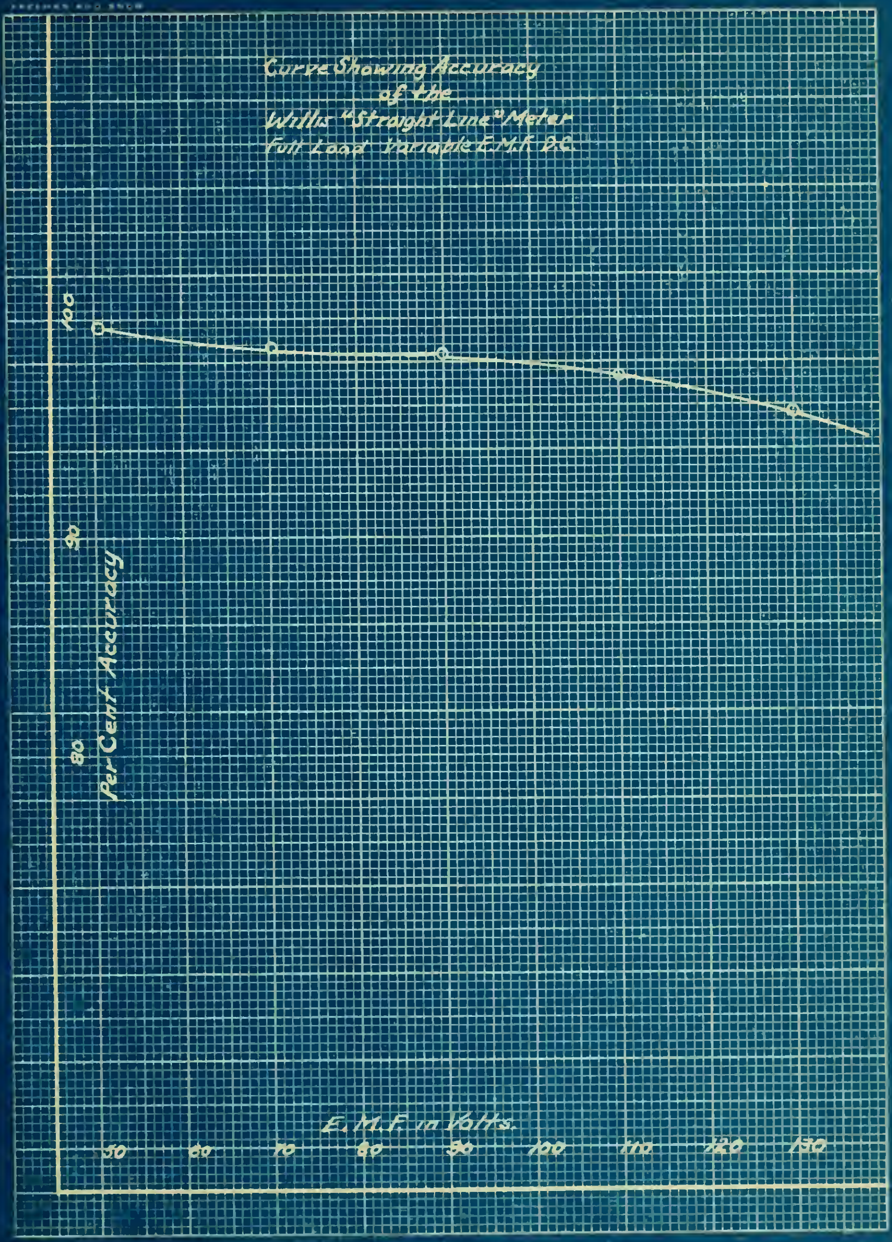
Amperes.	Rev.	True W.H.	Meter W.H.	% Accuracy.
.94	118	9.4	9.83	104.2
2.97	350	29.7	29.17	98.5
5.03	574	50.3	48.35	96.1
7.60	912	76.0	71.65	94.0



Curve Showing Accuracy of the Willis "Straight Line" Meter 100 Volts Variable Load D.C

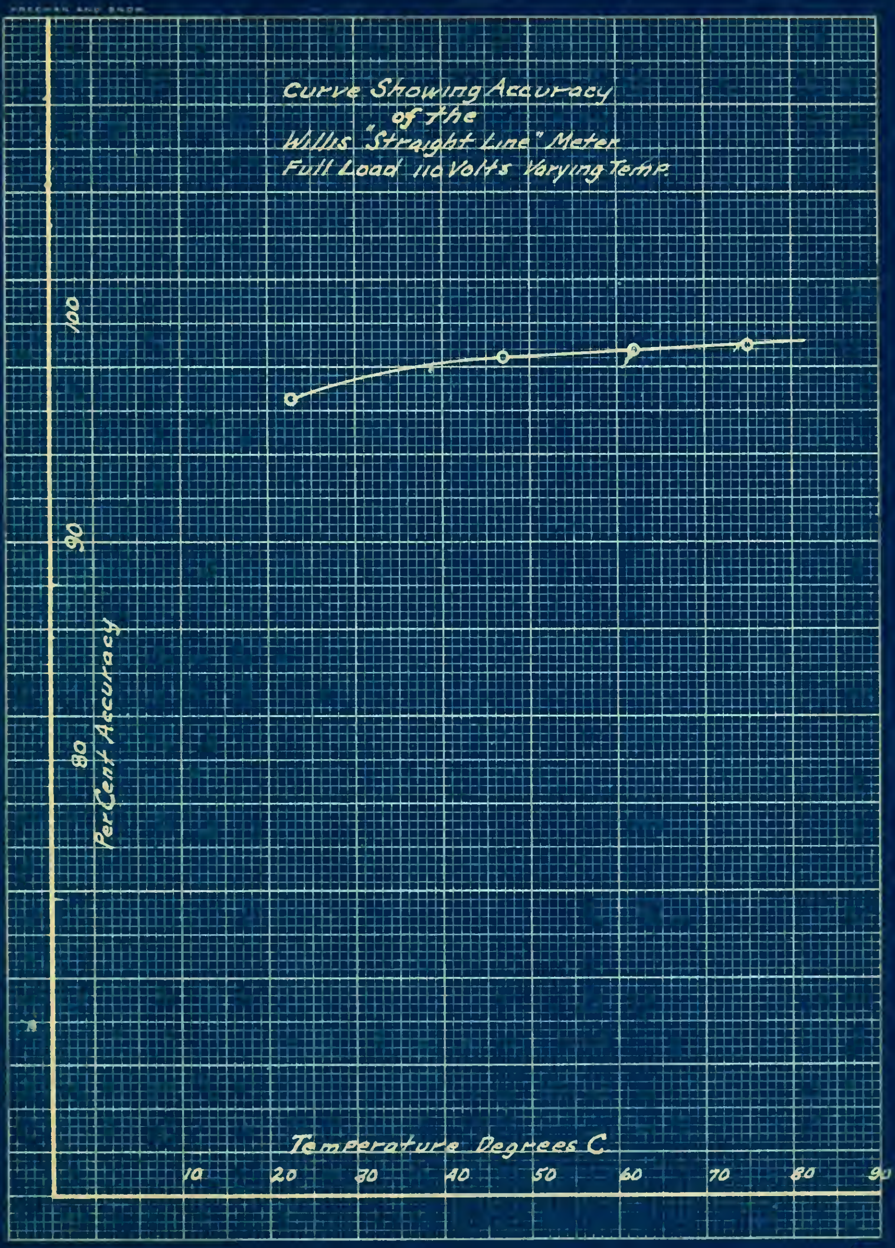
Data showing the effect of varying the pressure from 50 volts to 130 volts at full load.

Volts.	Rev.	True W.H.	Meter W.H.	% Accurracy.
50/6	308	25.9	25.8	99.6
70.3	420	35.4	35.0	98.7
90.2	537	45.4	44.6	98.4
110.0	645	55.3	53.8	97.4
129.9	751	65.3	62.6	95.7


Curve Showing Accuracy
of the
Willis "Straight Line" Meter
Full Load Variable E.M.F. D.C.
100
90
80
Per Cent Accuracy
E.M.F. in Volts.
50
60
70
80
90
100
110
120
130

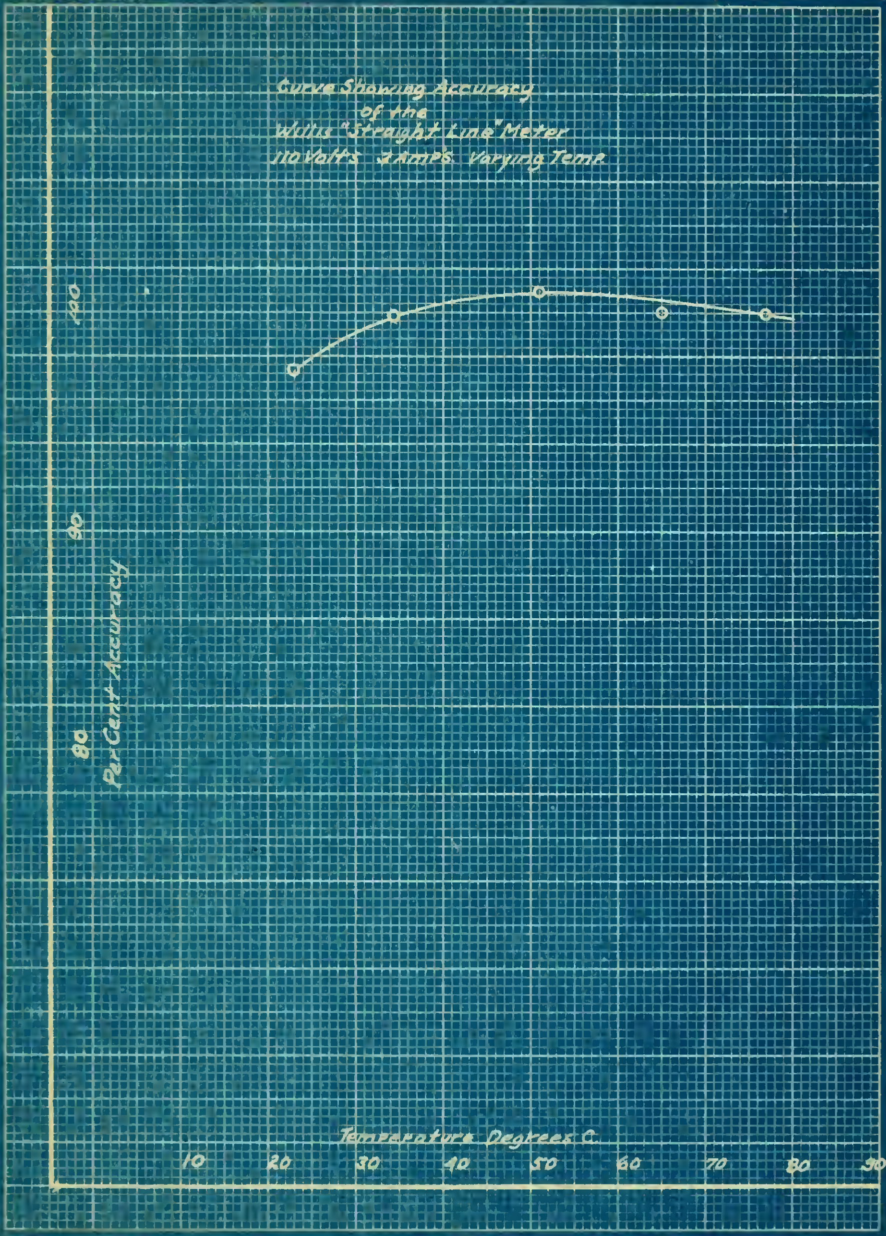
Data showing the effect of varying the temperature at 110 volts and full load.

Temp. Deg. C.	Rev.	True W.H.	Meter W.H.	% Accuracy.
23.2	642	55.4	53.6	96.65
47	654	55.4	54.6	98.50
62	657	55.4	54.7	98.70
75	660	55.4	54.8	98.90


FREEMAN AND SNOW
Curve Showing Accuracy
of the
Willis "Straight Line" Meter
Full Load 110 Volts Varying Temp.
Per Cent Accuracy
100
90
80
Temperature Degrees C.
10
20
30
40
50
60
70
80
90

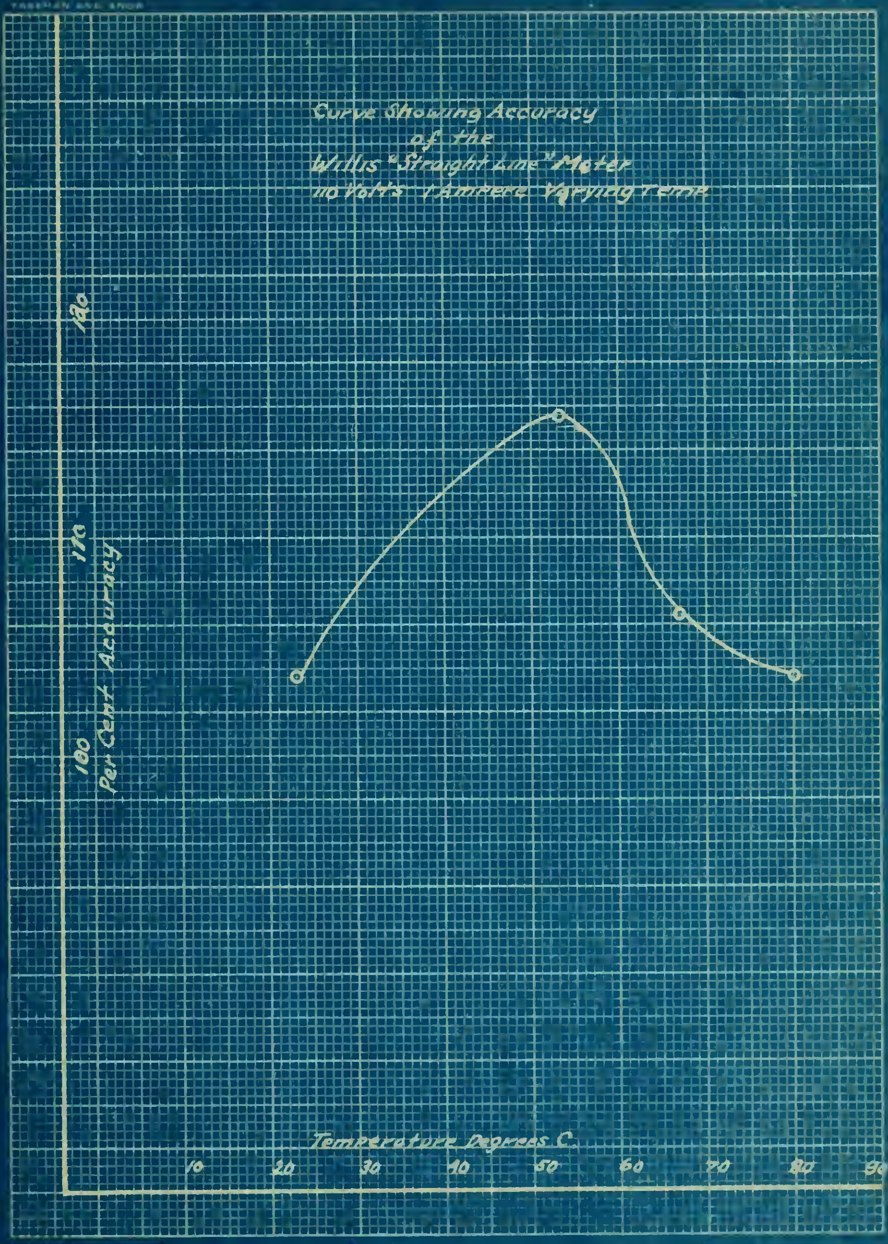
Data showing the effect of varying the temperature at 110 volts and 60% of full load.

Temp. Deg.C.	Rev.	True W.H.	Meter W.H.	% Accuracy.
23.2	381	32.7	31.8	97.3
51	396	32.7	33.0	101.0
65	393	32.7	32.7	100.0
77	393	32.7	32.7	100.0


Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts 3 Amps. Varying Temp.
100
90
80
Per Cent Accuracy
Temperature Degrees C.
10
20
30
40
50
60
70
80
90

Data showing the effect of varying the temperature at 110 volts and 20% of full load.

Temp. Deg.C.	Rev.	True W.H.	Meter W.H.	% Accuracy.
23.2	128.5	10.34	10.71	103.60
53	143	10.34	11.90	115.70
66	132	10.34	11.00	106.40
80	128.5	10.34	10.71	103.60


Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts 1 Ampere Varying Temp.
120
110
100
Per Cent Accuracy
Temperature Degrees C.
10
20
30
40
50
60
70
80
90

ALTERNATING CURRENT TESTS

The following alternating current tests were made upon the Willis "Straight Line" meter for each of the machines used:

1. Meter operated at 110 volts pressure with load varying from 0 to 50% overload.

2. Meter operated at full load but with pressure varying from 80 to 120 volts .

3. Meter operated at 110 volts with varying power factor (lagging current).

4. Meter operated at 120 volts with varying power factor(lagging current).

5. Meter operated at 100 volts with varying power factor(lagging current).

6. Meter operated at 110 volts with varying power factor(leading current).

7. Meter operated at 120 volts with varying power factor(leading current).

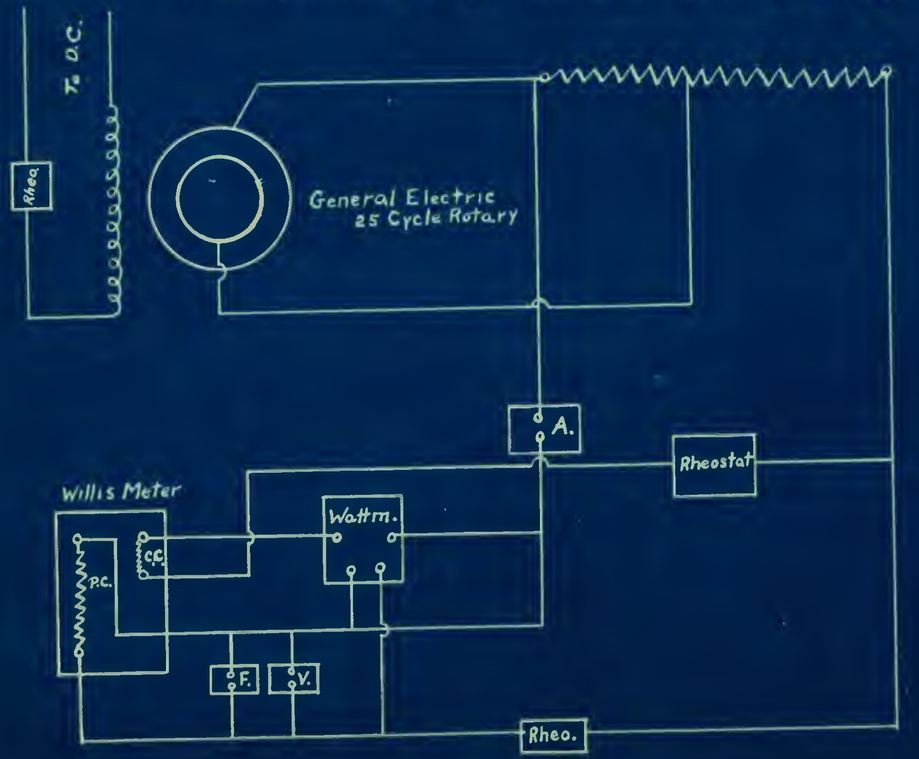
8. Meter operated at 100 volts with varying power factor(leading current).

As in the direct current tests six minute runs were taken. For each run the current, voltage, power consumption, and number of revolutions of the disc, were recorded.

The scheme of connections for the alternating current tests of the Willis "Straight Line" meter is shown on the following page. Although the scheme is for the General Electric 25 cycle rotary converter tests, it differs only slightly for the other machines.

Power was obtained from three different sources. First the Wagner Electric Alternator # 182 was used. This is a small machine having an output of 5 H.P. It operates at 110 volts with a normal speed of 60 cycles per second and gives a peaked wave. The second source of alternating current was from the General Electric 25 cycle rotary converter #17721. This machine was run from the direct current~~e~~ end but as the pressure obtained was only 85 volts it was stepped up by means of an auto-transformer. The e.m.f. curve as obtained from the rotary converter closely resembles that of a pure sine wave. The third and final machine to be used was the Holzer Cabot 60 cycle alternator# 16881. This machine has a capacity of 5 K.W. and gives a sine wave.

Scheme of Connections for A.C. Tests of Willis "Straight Line" Meter.



DATA AND CURVES
OF ALTERNATING CURRENT TESTS

Data showing the effect of varying the load from 0 to 50% overload when the meter was supplied with alternating current from the Wagner Electric 60 cycle alternator # 182.

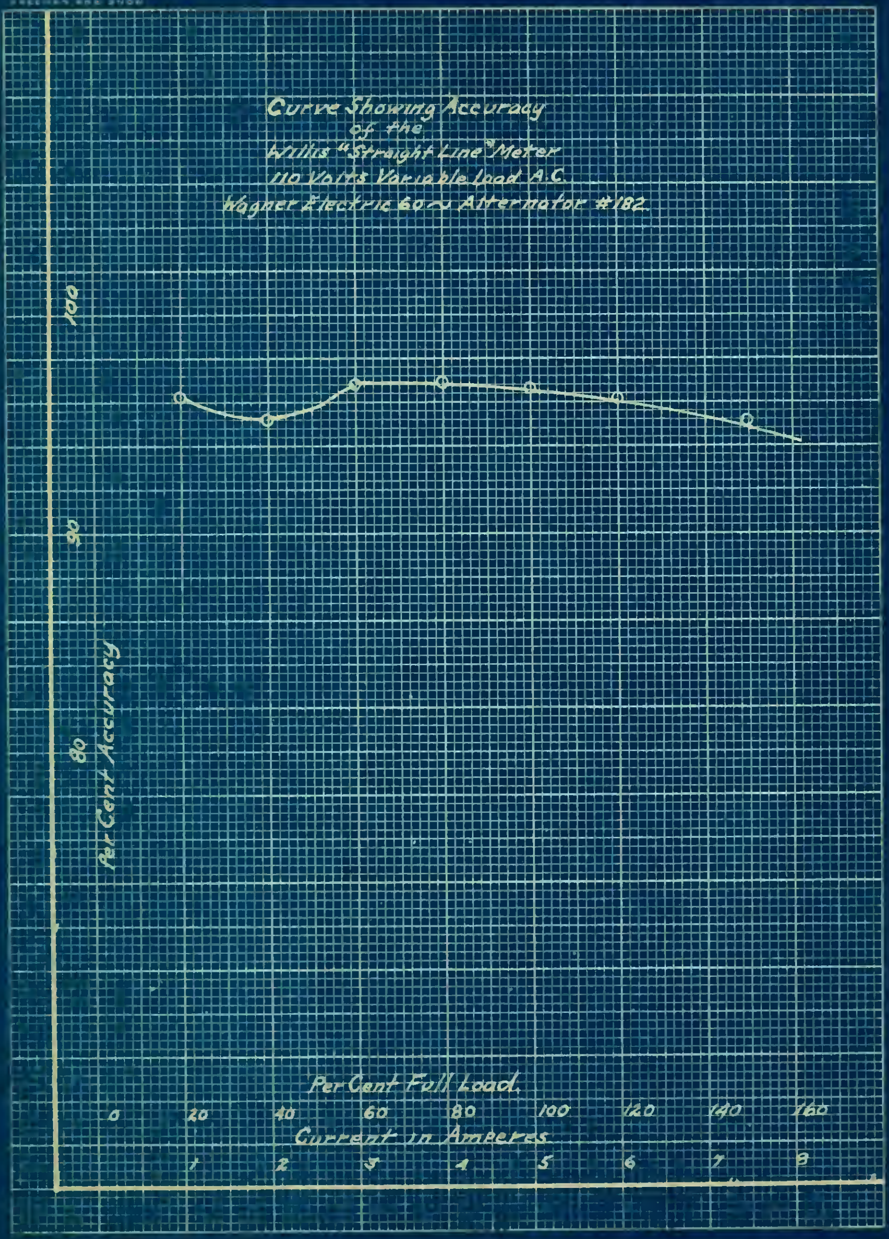
Constant e.m.f. of 110 volts.

Unity power factor.

Temperature 23.3) 24.0 C.

Duration of each run six minutes.

Amperes.	Rev.	Ture W.H.	Meter W.H.	% Accuracy.
1	128	11.1	10.66	96.3
2	252	22.1	21.00	95.2
3	383	33.0	31.90	96.8
4	514	44.2	42.80	96.8
5	642	55.3	53.50	96.6
6	770	66.3	64.15	96.2
7.5	950	83.0	79.00	95.1


Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts Variable load A.C.
Wagner Electric 60 ~ Alternator #182
100
90
80
Per Cent Accuracy
Per Cent Full Load.
0
20
40
60
80
100
120
140
160
Current in Amperes
1
2
3
4
5
6
7
8

Data showing the effect of varying the pressure from 80 volts to 120 volts when the meter was supplied with alternating current from the Wagner Electric 60 cycle alternator # 182.

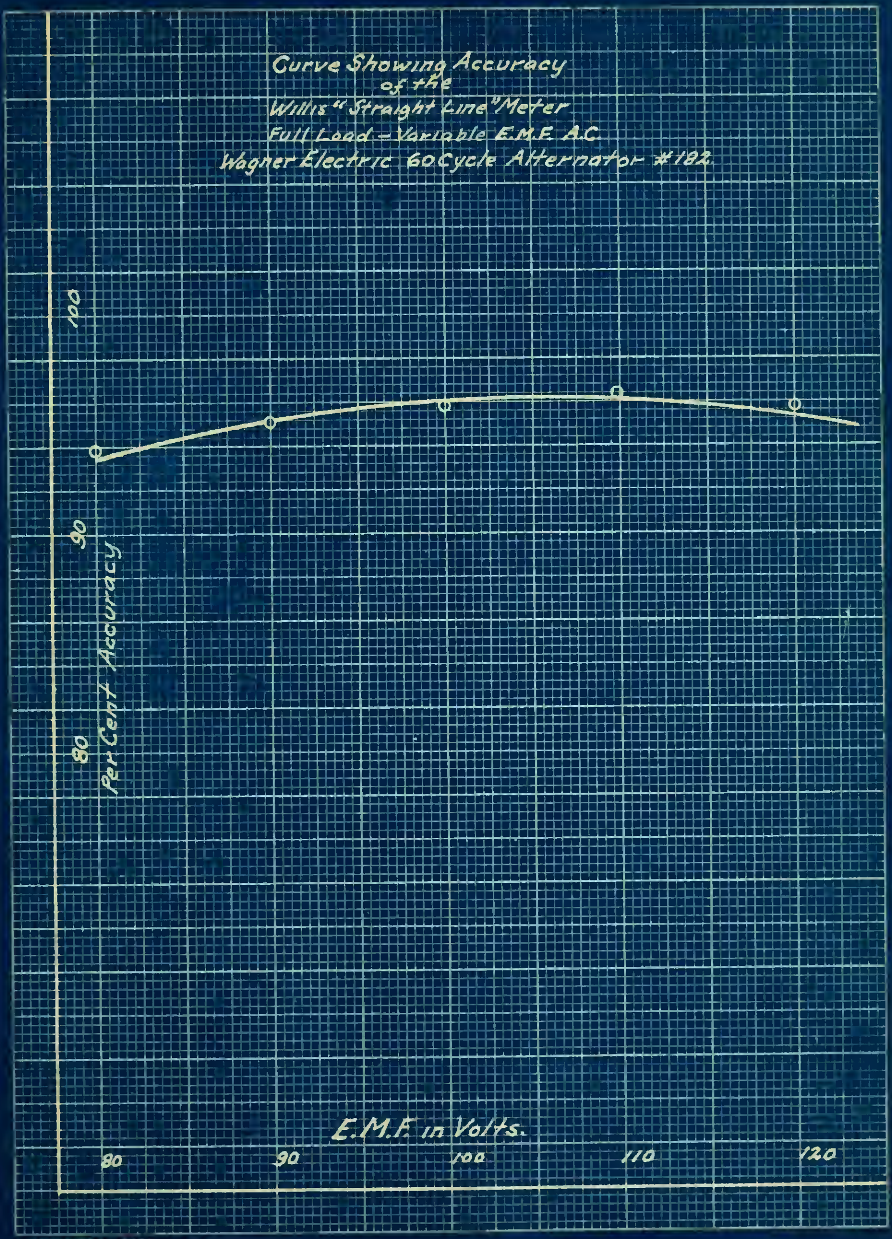
Unity power factor.

Full load.

Temperature 23.8 --- 24.3 C.

Duration of each run six minutes.

Volts	Rev.	True W.H.	Meter W.H.	% Accuracy.
79.7	451	40.1	37.6	93.8
89.8	513	45.2	42.9	95.1
99.9	580	50.3	48.3	95.8
110.0	642	55.5	53.6	96.4
120.0	681	60.7	56.8	93.8



Curve Showing Accuracy
of the
Willis "Straight Line" Meter
Full Load – Variable E.M.F. A.C.
Wagner Electric 60 Cycle Alternator #182

Data showing the effect of varying the power factor (lagging current) when the meter was supplied with alternating current from the Wagner Electric 60 cycle alternator # 182.

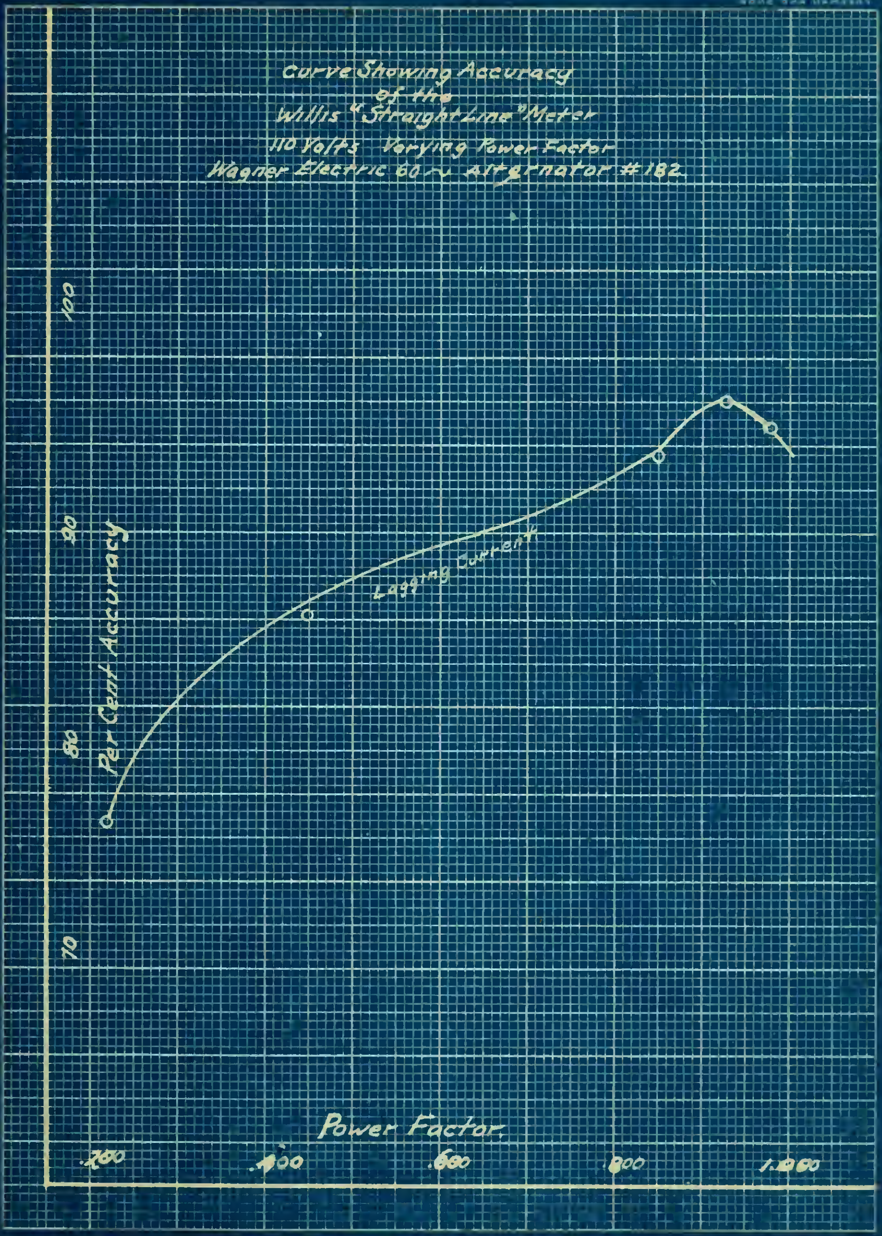
Constant e. m. f. of 110 volts.

Variable current.

Temperature 23.7--- 24.1 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
3	.221	67	7.3	5.6	76.7
3	.848	314	28.0	26.1	93.5
5	.931	590	51.2	49.2	96.1
7.5	.977	918	80/7	76.5	94.9


Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts Varying Power Factor
Wagner Electric 60 ~ Alternator #182
100
90
80
70
Per Cent Accuracy
Lagging Current
Power Factor
.200
.400
.600
.800
1.000

Data showing the effect of varying the power factor (lagging current) when the meter was supplied with alternating current from the Wagner Electric 60 cycle alternator # 182.

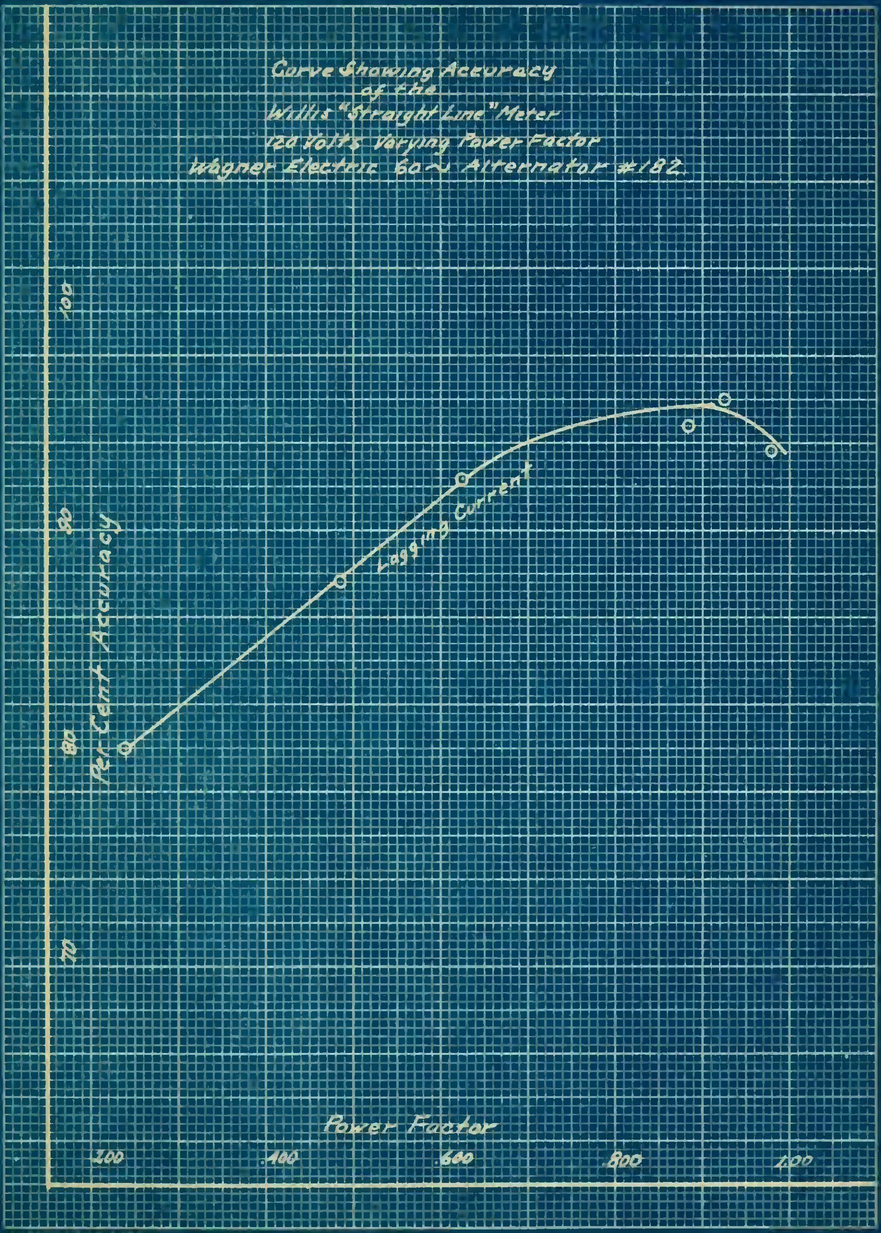
Constant e.m.f. of 120 volts.

Variable current.

Temperature 23.7 --- 24.1 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
3	.241	58	8.7	6.96	80.0
3	.484	128	17.5	15.33	87.7
4	.625	232	30.0	27.75	92.3
5	.885	419	53.0	50.20	94.8
5	.925	445	55.4	53.27	96.0
7.5	.978	690	88.2	82.71	93.6



Curve Showing Accuracy
of the
Willis "Straight Line" Meter
120 Volts Varying Power Factor
Wagner Electric 60~ Alternator #182

Data showing the effect of varying the power factor (lagging current) when the meter was supplied with alternating current form the Wagner Electric 60 cycle alternator # 182.

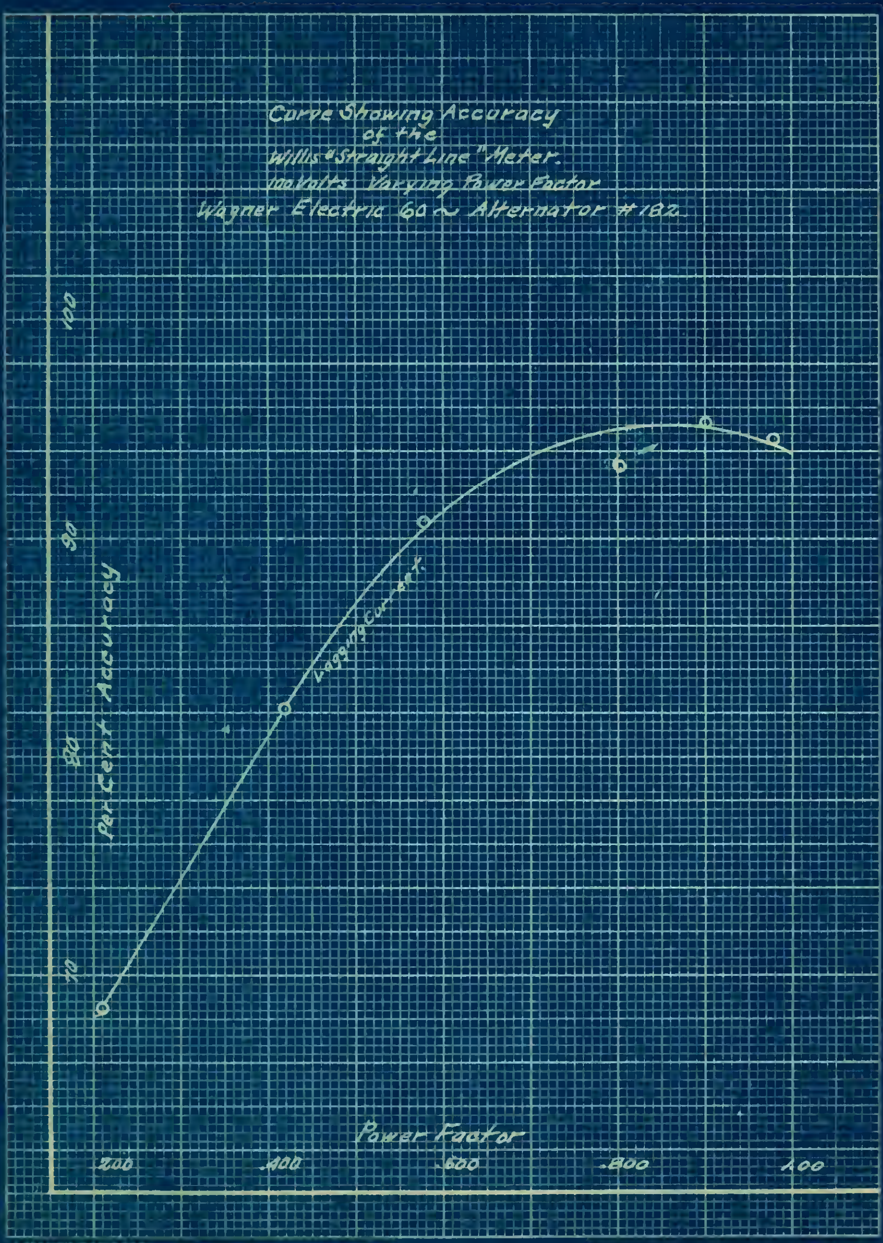
Constant e.m.f. of 100 volts.

Variable current.

Temperature 23.7 --- 24.1 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
3.0	.210	52	6.3	4.33	68.5
3.0	.423	125	12.7	10.4	82.2
4.2	.578	265	24.3	22.1	90.9
5.0	.804	445	40.2	37.1	92.6
5.1	.902	526	46.0	43.8	95.3
7.5	.980	836	73.6	69.6	94.6


Curve Showing Accuracy
of the
Willis "Straight Line" Meter.
100 Volts Varying Power Factor
Wagner Electric 60 ~ Alternator #182.

Data showing the effect of varying the power factor (leading current) when the meter was supplied with alternating current from the Wagner Electric 60 cycle alternator # 182.

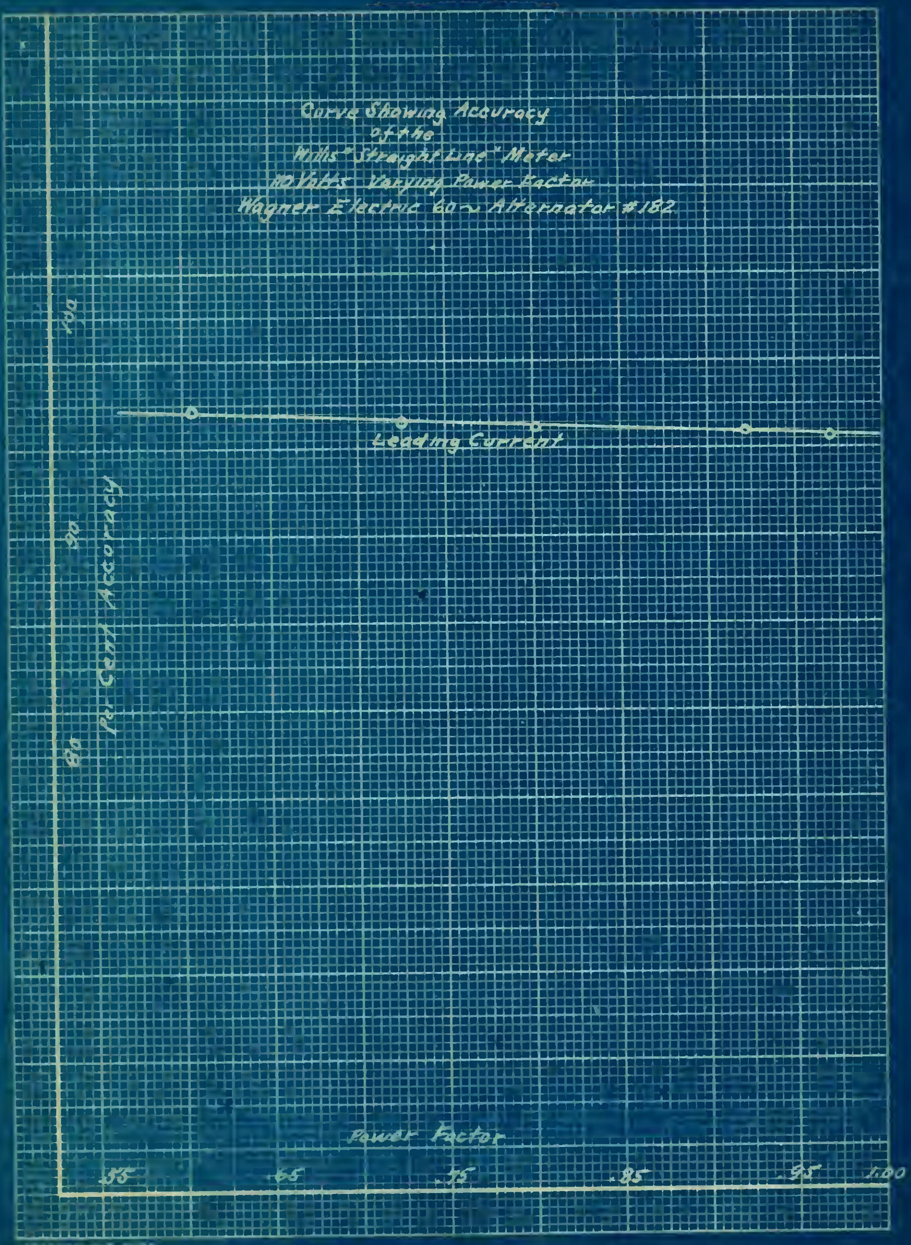
Constant e.m.f. of 110 volts.

Variable current.

Temperature 23.9 --- 24.2 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.25	.608	172	15.0	14.4	95.7
3.52	.724	321	28.1	26.8	95.3
4.50	.805	451	39.8	37.6	94.6
6.30	.922	724	63.9	60.3	94.4
7.74	.970	930	82.5	77.3	93.8



Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts Varying Power Factor
Wagner Electric 60~ Alternator #182

Data showing the effect of varying the power factor (leading current) when the meter was supplied with alternating current from the Wagner Electric 60 cycle alternator # 182.

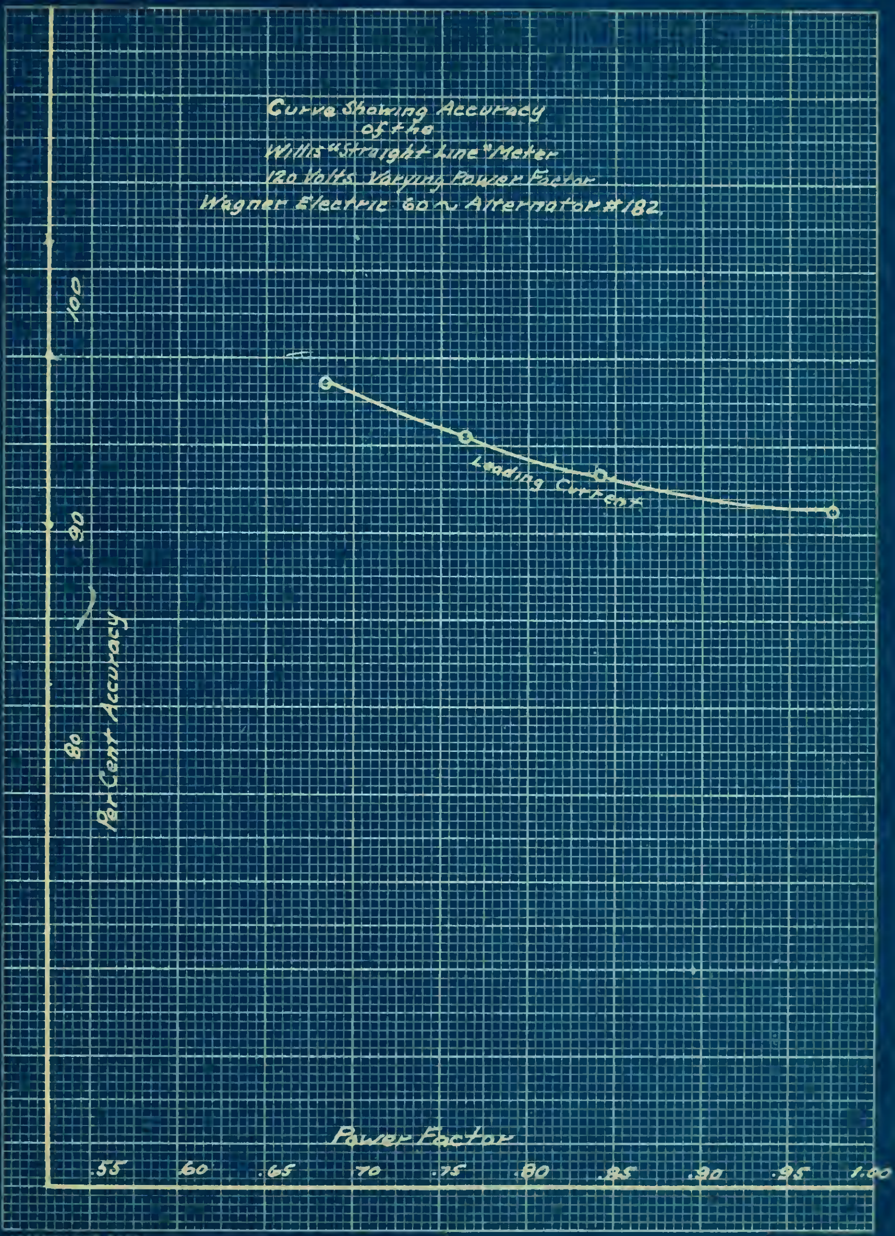
Constant e.m.f. of 120 volts.

Variable current.

Temperature 23.9 --- 24.6 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.54	.685	243	20.9	20.3	96.8
3.32	.766	347	30.6	28.9	94.5
4.31	.846	487	43.8	40.6	92.7
7.26	.975	928	84.9	77.3	91.3



Curve Showing Accuracy
of the
Willis "Straight Line" Meter
120 Volts. Varying Power Factor
Wagner Electric 60 ~ Alternator #182.

Data showing the effect of varying the power factor (leading current) when the meter was supplied with alternating current from the Wagner Electric 60 cycle alternator #182.

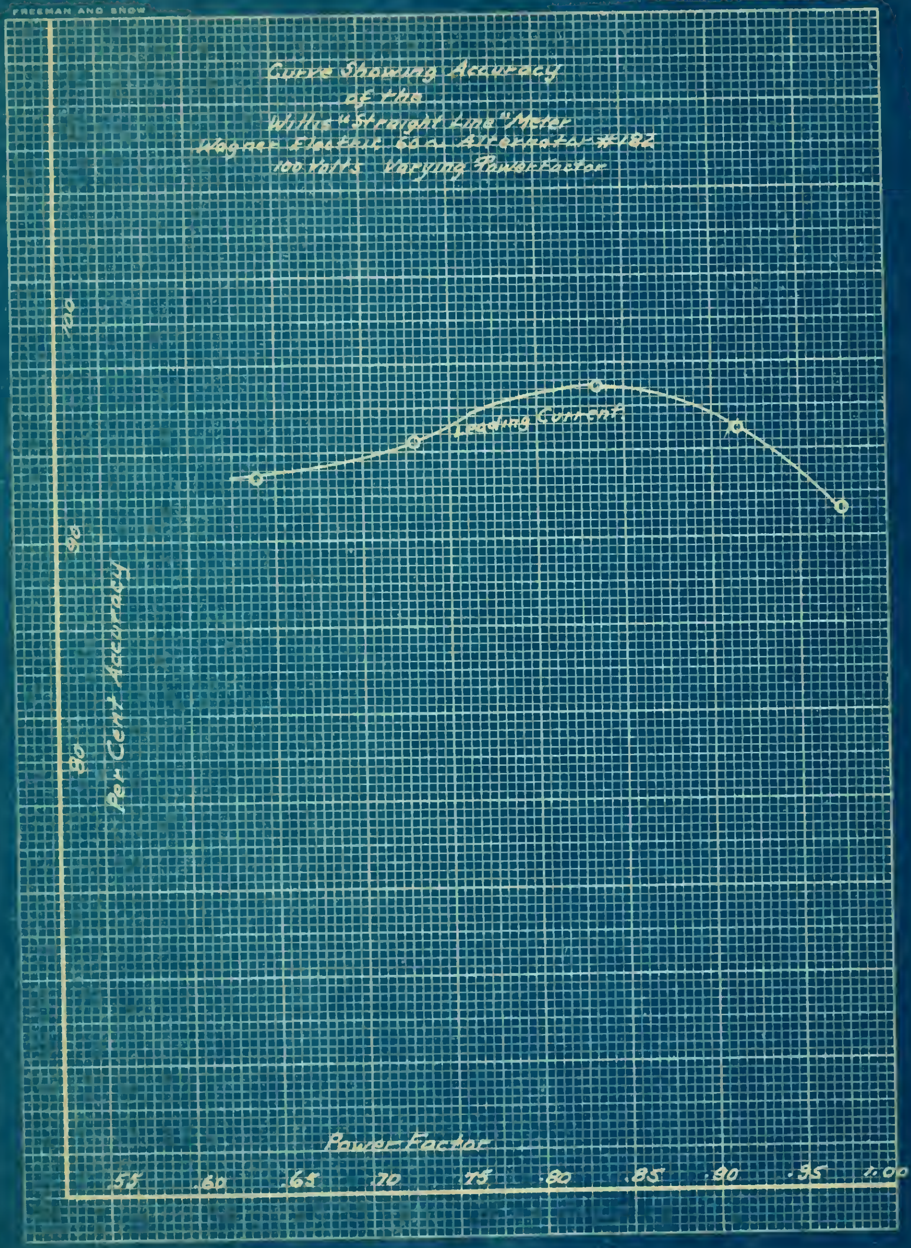
Constant e.m.f. of 100 volts.

Variable current.

Temperature 24.2 --- 24.8 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.33	.640	166	14.9	13.8	92.8
3.50	.730	296	26.1	24.7	94.5
4.36	.836	425	36.5	35.4	96.9
6.34	.915	695	58.0	55.1	95.1
7.66	.973	815	74.6	68.0	91.3



Curve Showing Accuracy
of the
Willis "Straight Line" Meter
Wagner Electric 60~ Alternator #182
100 Volts Varying Power Factor

Data showing the effect of varying the load from 0 to 50% overload when the meter was supplied with alternating current from the General Electric 25 cycle rotary converter # 17721.

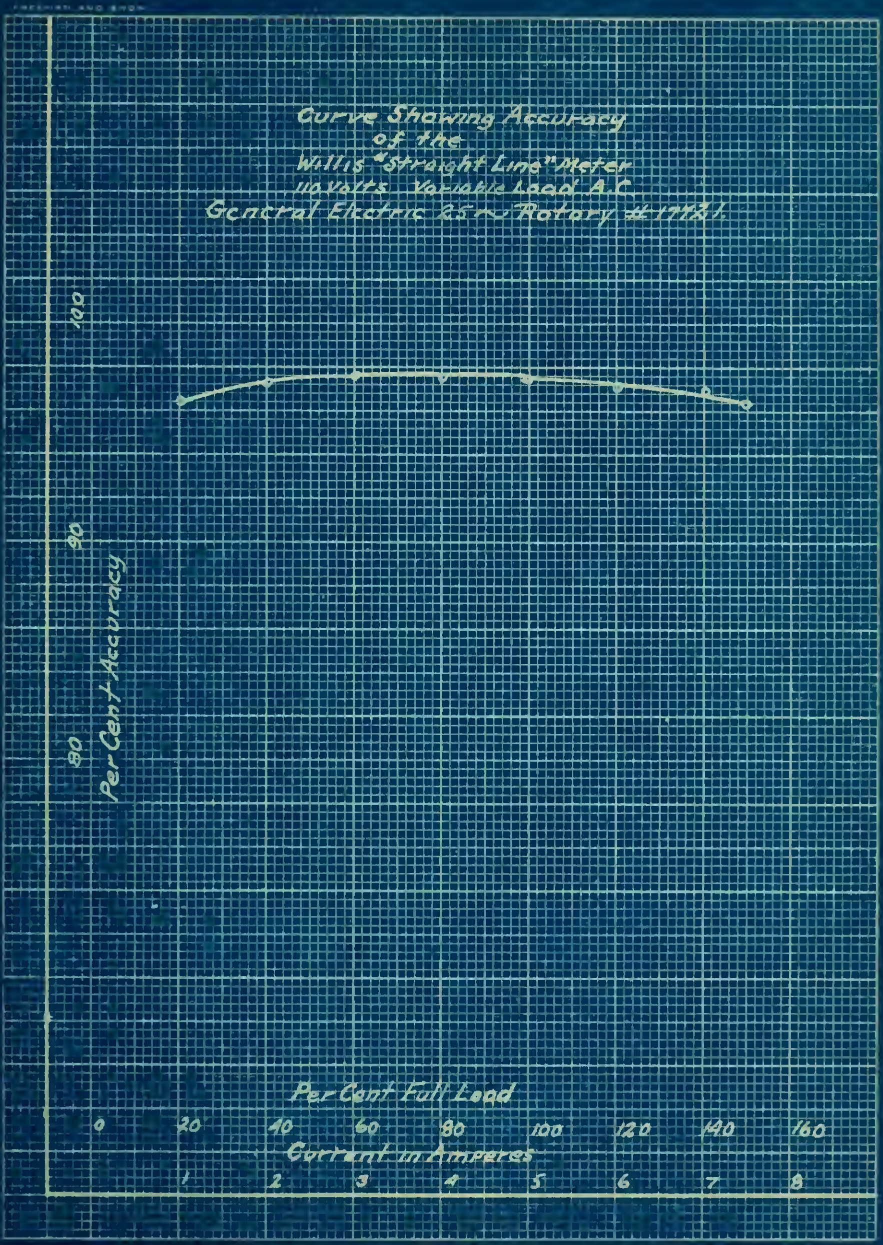
Constant e.m.f. of 110 volts.

Unity power factor.

Temperature 22.6 -- 23.6 C.

Duration of each run six minutes.

Amperes.	Rev.	True W.H.	Meter W.H.	% Accuracy.
1	127	11	10/6	96.5
2	257	22	21.4	97.1
3	387	33	32.2	97.4
4	512	44	42.7	97.2
5	646	55	53.7	97.3
6	767	66	64.0	97.0
7.5	956	82.5	79.5	96.3



Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts Variable Load A.C.
General Electric 25 ~ Rotary #17781.

Data showing the effect of varying the pressure from 80 volts to 120 volts when the meter was supplied with alternating current from the General Electric 25 cycle rotary converter# 17721.

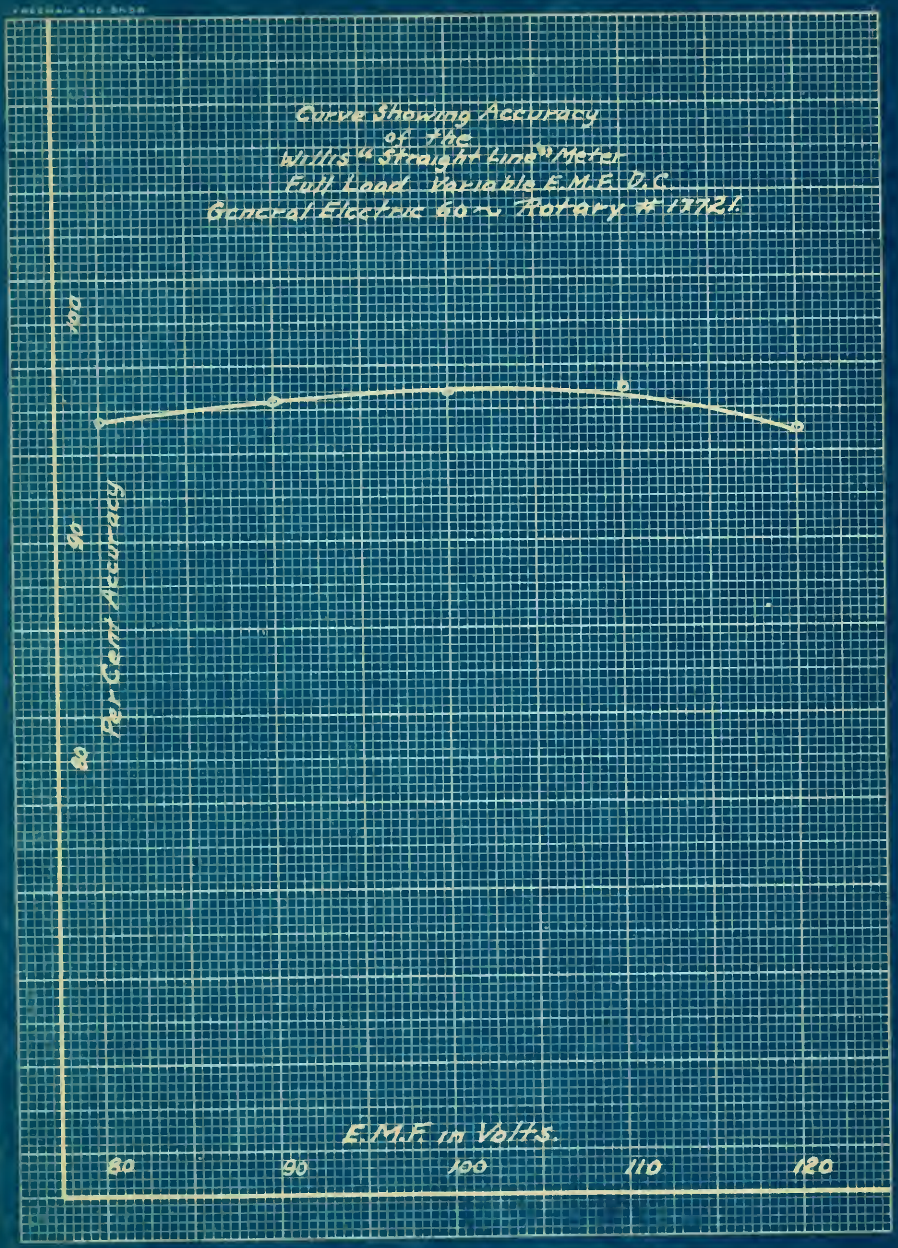
Unity power factor.

Full load.

Temperature 23.1 --- 23.6 C.

Duration of each run six minutes.

Volts.	Rev.	True W.H.	Meter W.H.	% Accuracy.
79.7	457	39.8	38.1	95.4
89.8	520	44.9	43.2	96.3
99.9	580	50.0	48.4	96.8
110.0	646	55.0	53.7	97.3
120.0	687	60.0	57.1	95.0

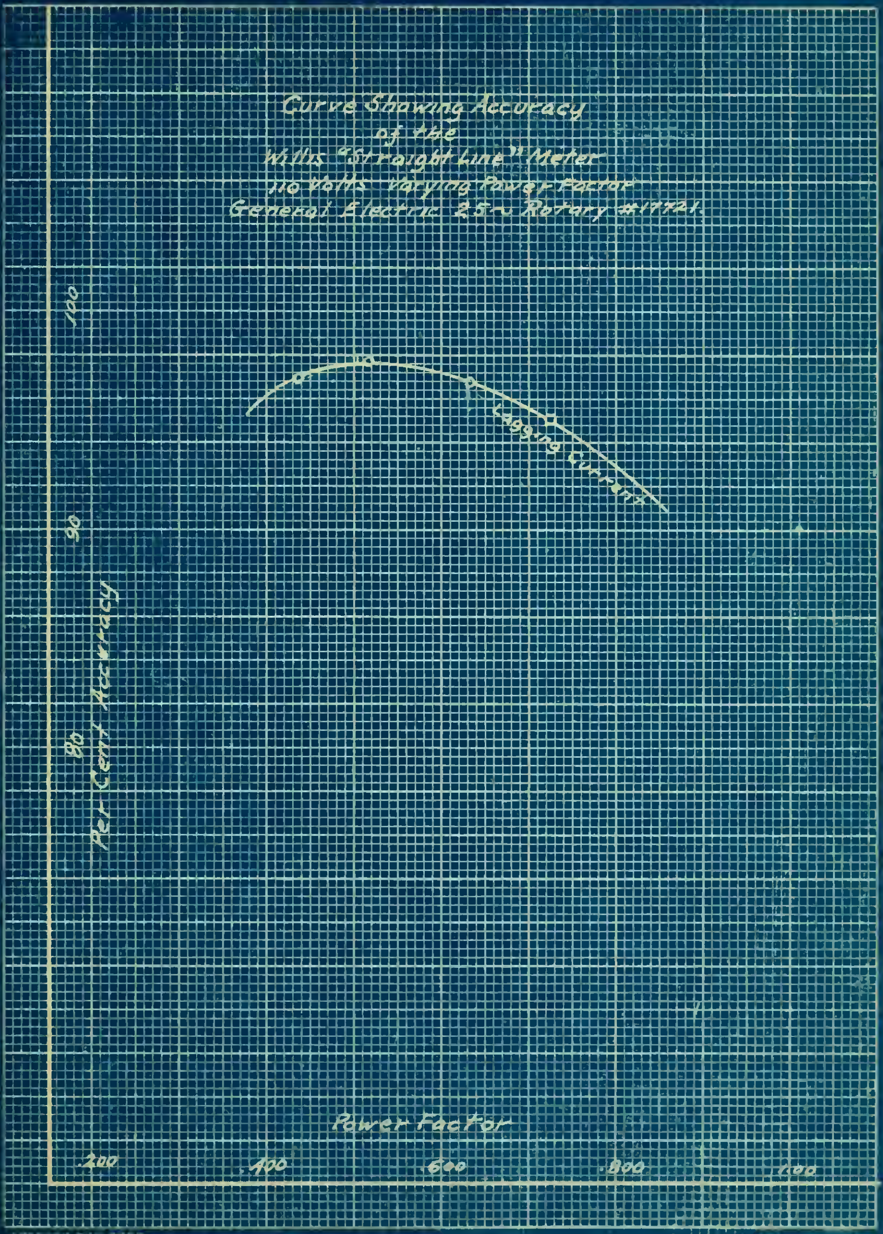

Curve Showing Accuracy
of the
Willis "Straight Line" Meter
Full Load Variable E.M.F. D.C.
General Electric 60~ Rotary # 17721.

Data showing the effect of varying the power factor (lagging current) at 110 volts and varying load when the meter was supplied with 25 cycle alternating current from the General Electric rotary converter # 17721.

Temperature 23.4   23.9 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.20	.438	124	10.6	10.3	96.8
4.38	.518	293	25.0	24.5	97.8
6.51	.628	522	45.1	43.5	96 .6
7.78	.721	702	61.8	58.5	94.7



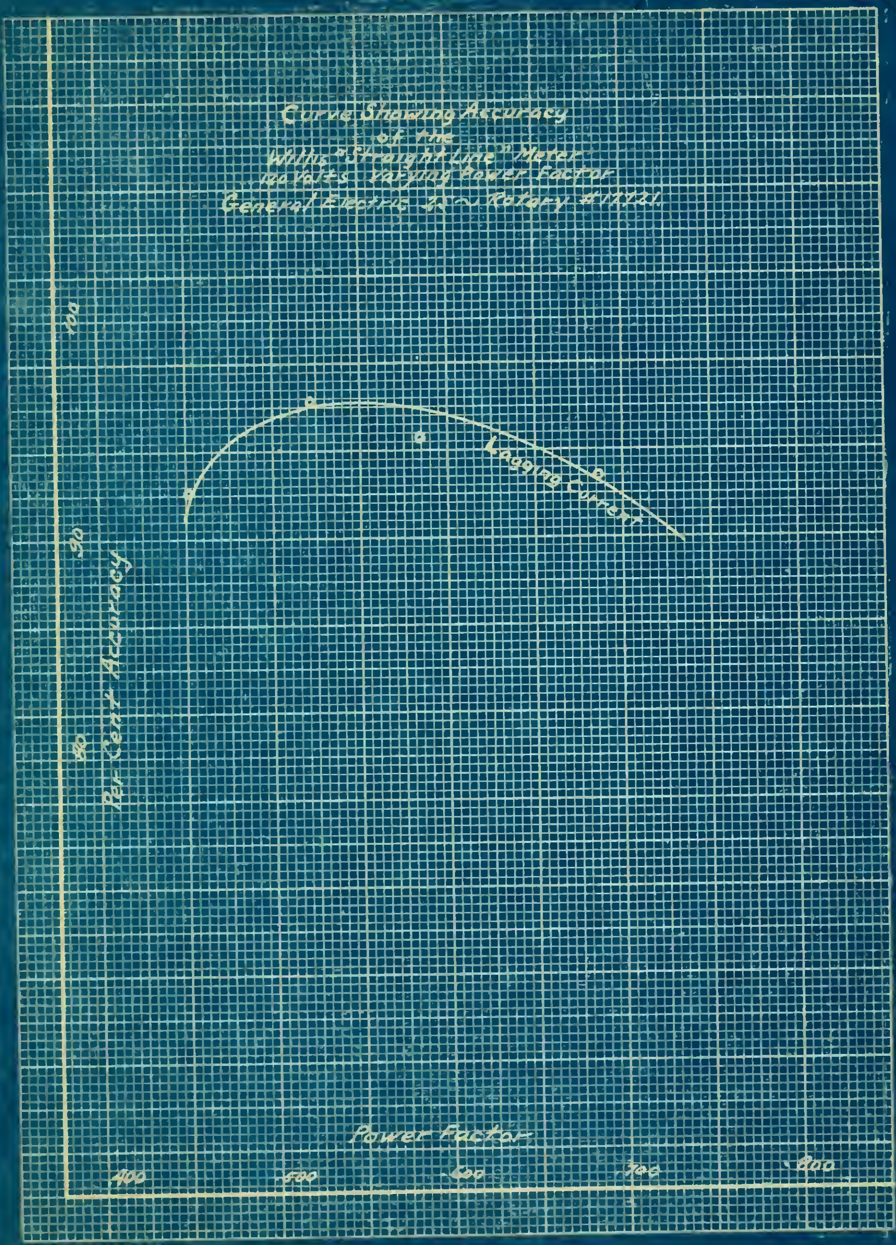
Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts Varying Power Factor
General Electric 25~ Rotary #17721.

Data showing the effect of varying the power factor (lagging current) at 120 volts and varying load when the meter was supplied with 25 cycle alternating current from the General Electric rotary converter # 17721.

Temperature 23.6 --- 24.0 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.33	.451	139	12.6	11.6	92.0
4.41	.520	318	27.5	26.5	96.3
6.02	.583	478	42.1	39.8	94.4
7.25	.686	669	59.9	55.7	93.0



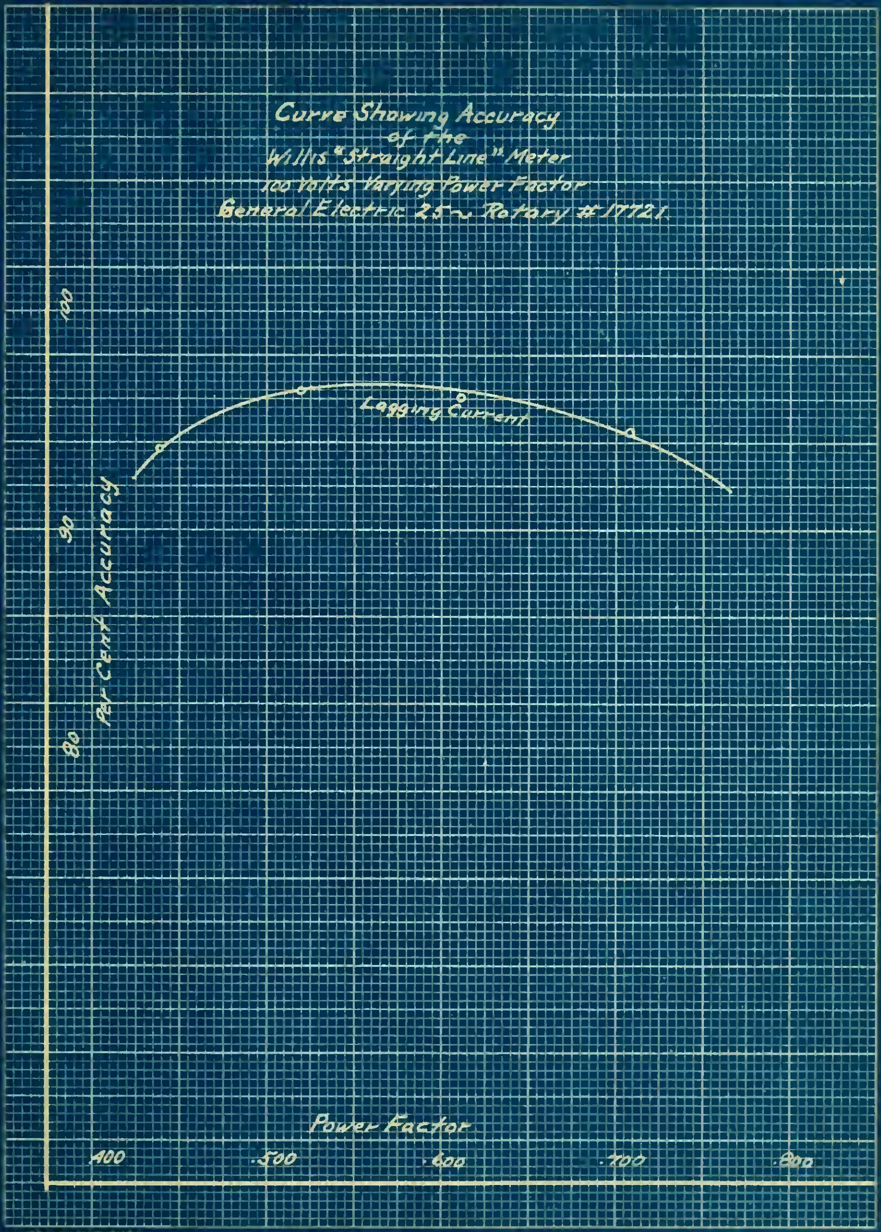
Curve Showing Accuracy
of the
Willis "Straight Line" Meter
100 Volts Varying Power Factor
General Electric 60~ Rotary #17121.

Data showing the effect of varying the power factor (lagging current) at 100 volts and varying load when the meter was supplied with 25 cycle alternating current from the General Electric rotary converter # 17721.

Temperature 23.7 --- 24.1 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.25	.437	110	9.83	9.2	93.8
4.48	.521	271	23.4	22.6	96.6
6.15	.609	432	37.4	36.0	96.2
7.32	.712	588	52.0	49.1	94.5

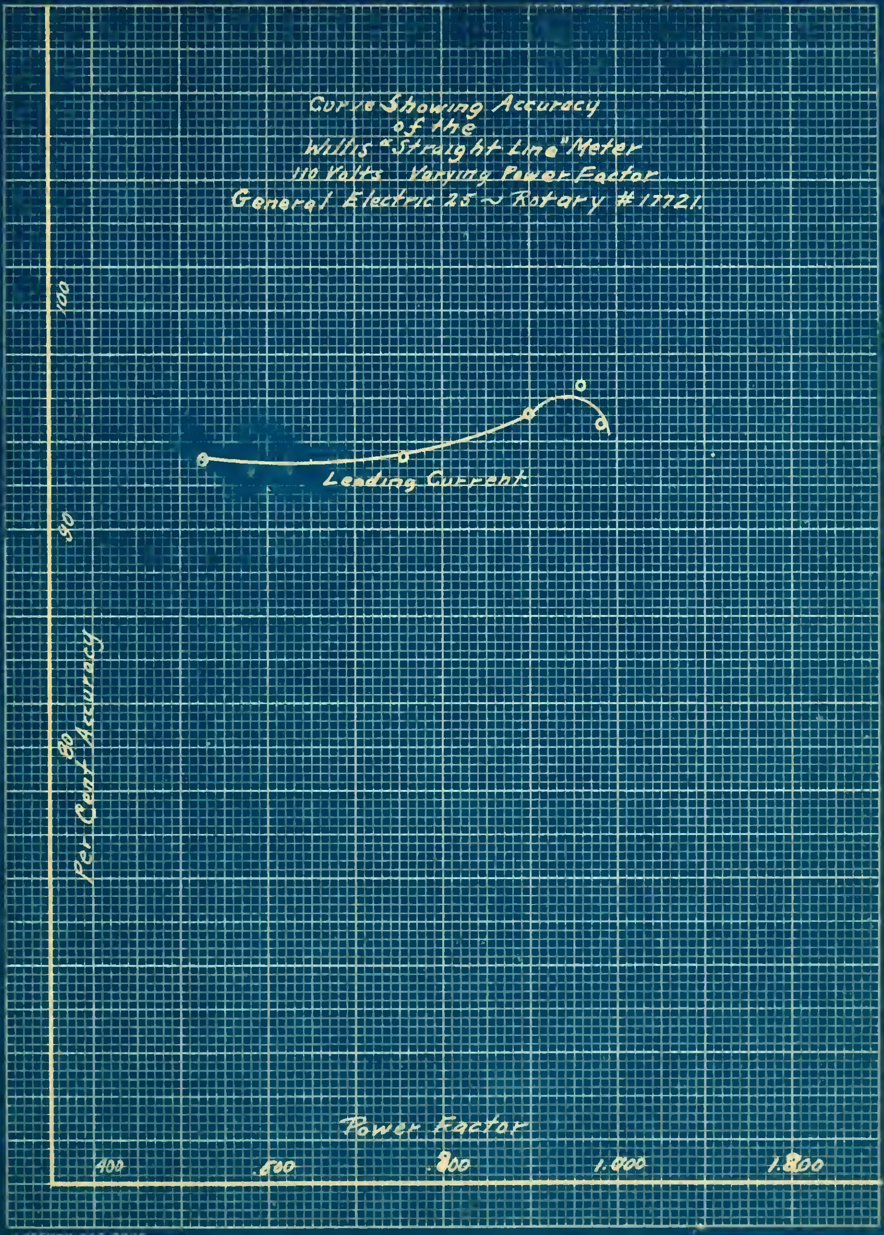

Curve Showing Accuracy
of the
Willis "Straight Line" Meter
100 Volts Varying Power Factor
General Electric 25~ Rotary #17721.
Lagging Current
100
90
80
Per Cent Accuracy
Power Factor
.400
.500
.600
.700
.800

Data showing the effect of varying the power factor (leading current) at 110 volts and varying load when the meter was supplied with 25 cycle alternating current from the General Electric rotary converter # 17721.

Temperature 24.0 --- 24.3 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.00	.527	130	11.6	10.8	93.1
3.07	.755	285	25.5	23.7	93.4
4.31	.897	489	42.5	40.7	95.8
6.92	.960	846	73.1	70.4	96.6
7.85	.980	961	84.6	80.1	94.7



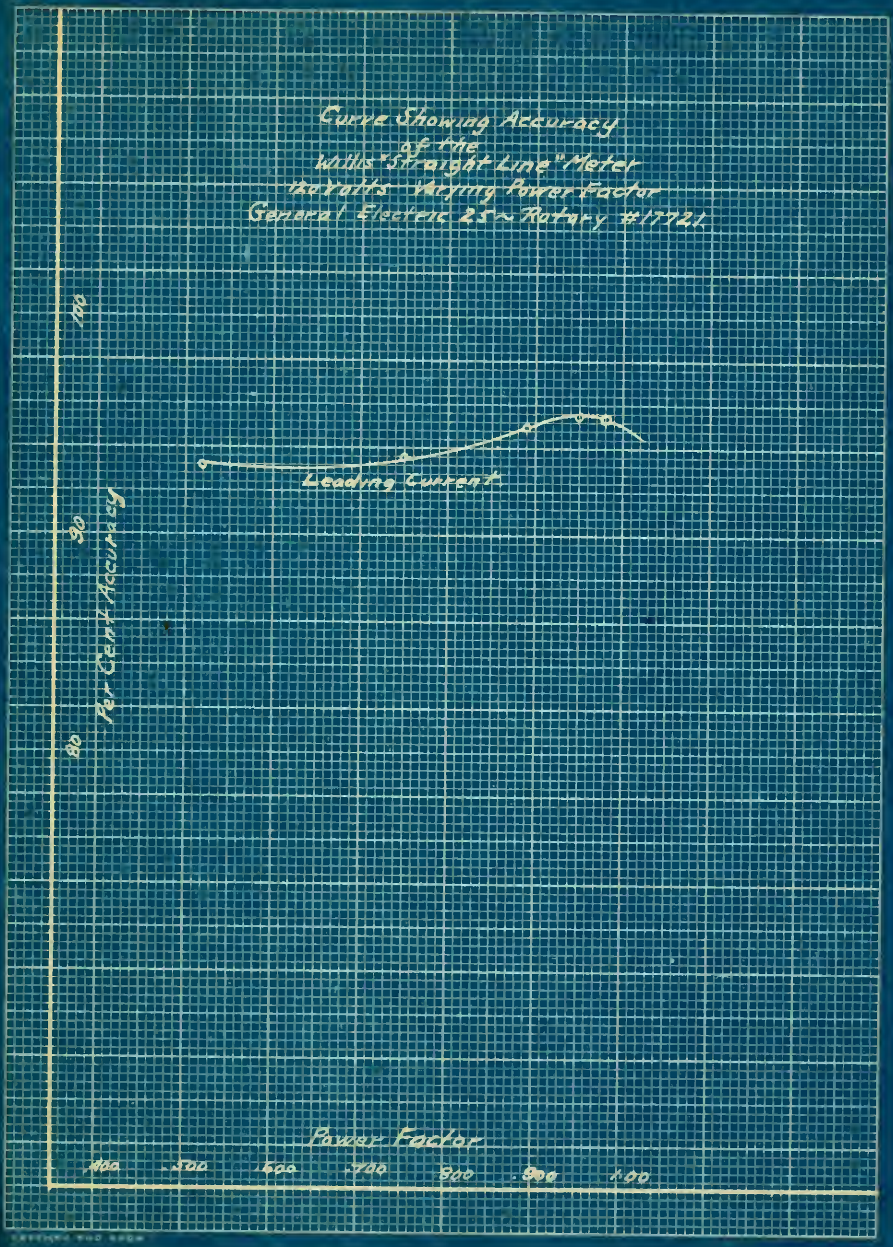
Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts Varying Power Factor
General Electric 25 ~ Rotary #17721.

Data showing the effect of varying the power factor (leading current) at 120 volts and varying load when the meter was supplied with 25 cycle alternating current from the General Electric rotary converter # 17721.

Temperature 24.2 --- 24.7 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy
2.03	.522	142	12.7	11.83	93.2
3.05	.751	309	27.6	25.7	93.6
4.32	.890	524	46.0	43.7	94.9
6.80	.951	870	75.7	72.3	95.5
7.72	.980	1037	90.7	86.5	95.2



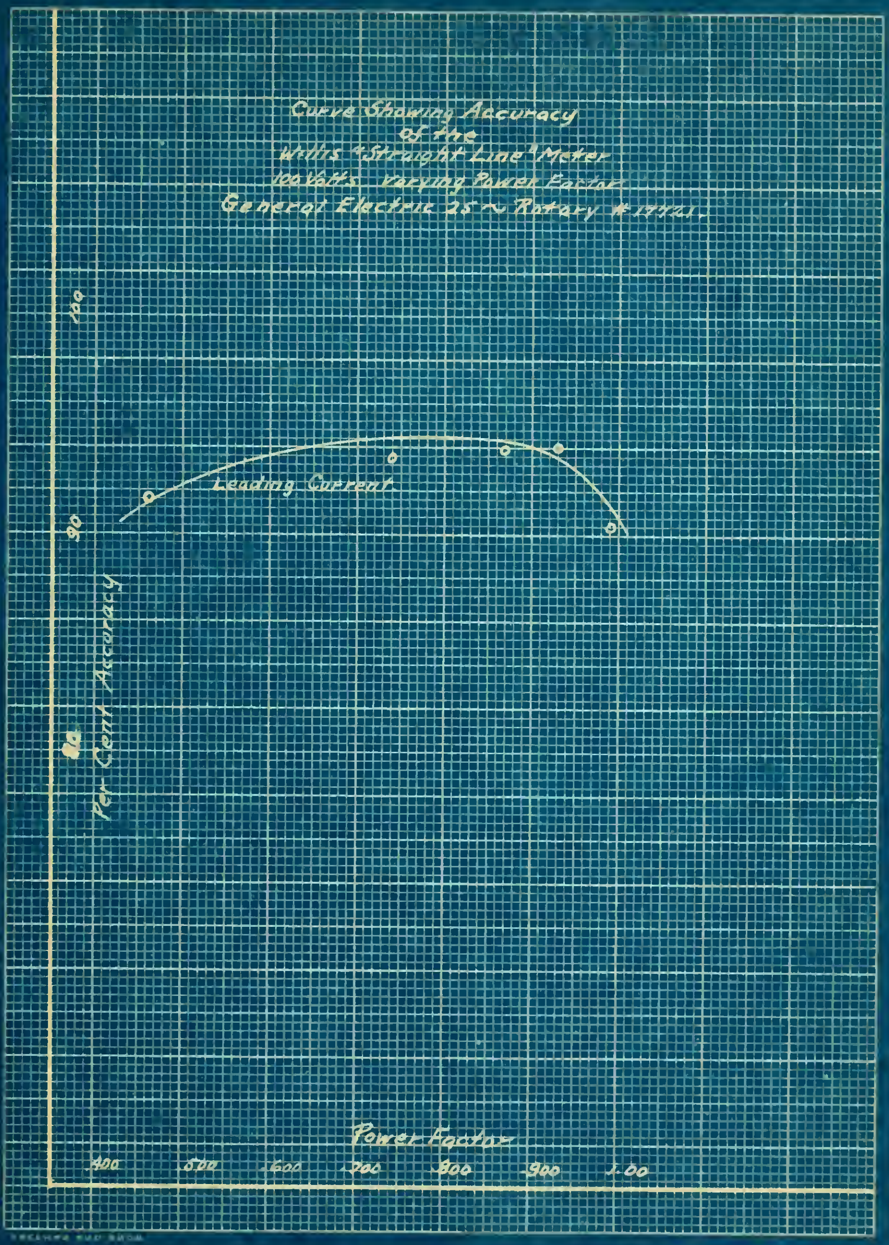
Curve Showing Accuracy
of the
Willis "Straight Line" Meter
120 Volts Varying Power Factor
General Electric 25~ Rotary #17721

Data showing the effect of varying the power factor (leading current) at 100 volts and varying load when the meter was supplied with 25 cycle alternating current from the General Electric rotary converter # 17721.

Temperature 24.3 --- 24.7 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
1.66	.460	84	7.64	7.0	91.6
2.93	.738	242	21.6	20.2	93.5
4.03	.869	395	35.0	32.9	94.0
6.49	.932	688	60.6	57.3	94.2
8.02	.990	864	79.4	71.9	90.3


Curve Showing Accuracy
of the
Willis "Straight Line" Meter
100 Volts. Varying Power Factor
General Electric 25 ~ Rotary #17721.
100
90
80
Per Cent Accuracy
Leading Current
Power Factor
.400
.500
.600
.700
.800
.900
1.00

Data showing the effect of varying the load from 0 to 50% overload when the meter was supplied with alternating current from the Holzer Cabot 60 cycle alternator # 16881.

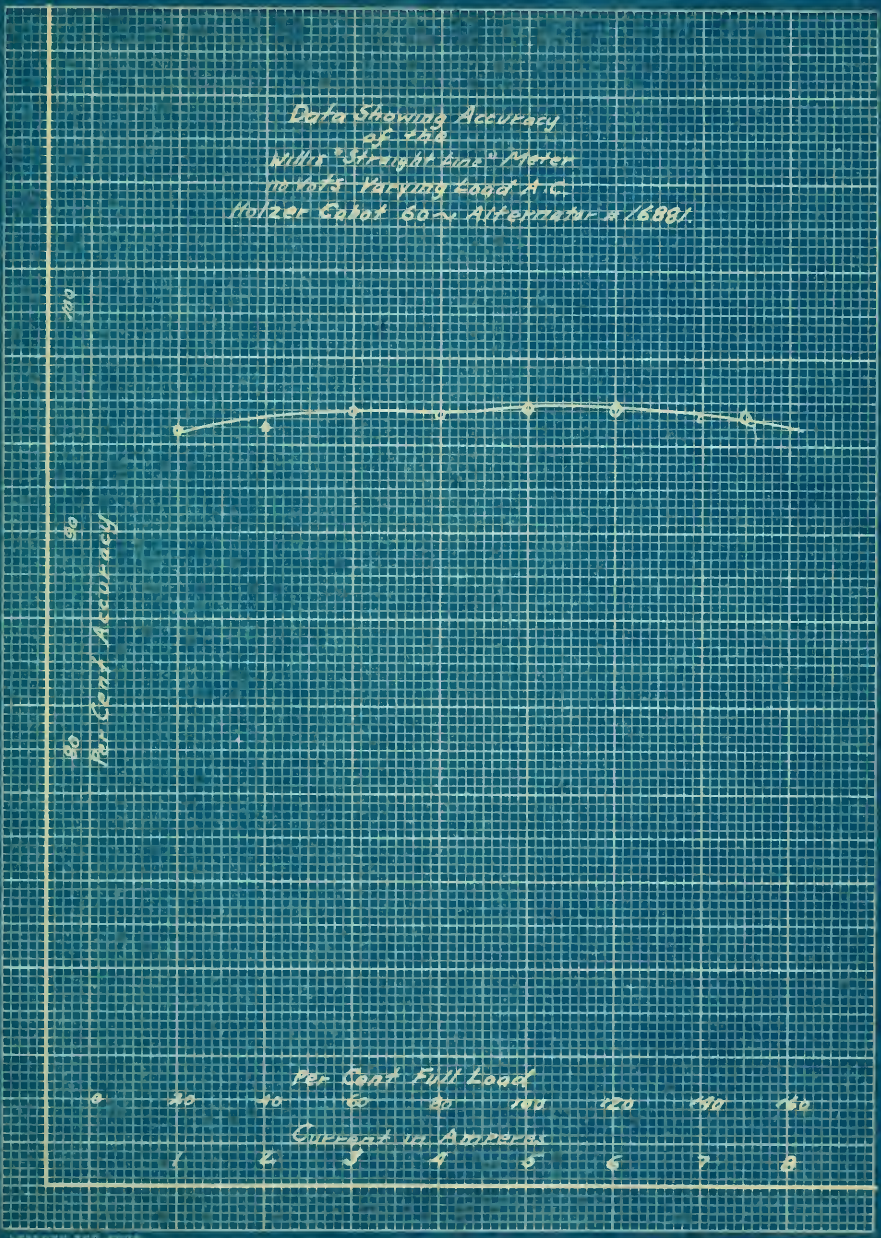
Constant e.m.f. of 110 volts.

Unity power factor.

Temperature 22.6 --- 23.3 C.

Duration of each run six minutes.

Amperes.	Rev.	True W.H.	Meter W.H.	% Accuracy.
1	128	11.1	10.5	94.6
2	256	22.5	21.3	94.8
3	388	33.7	32.3	95.7
4	512	44.7	42.6	95.5
5	646	56.0	53.8	95.9
6	770	66.8	64.2	95.9
7.5	949	83.0	79.0	95.3



Data Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts Varying Load A.C.
Holzer Cabot 60~ Alternator # 16881.

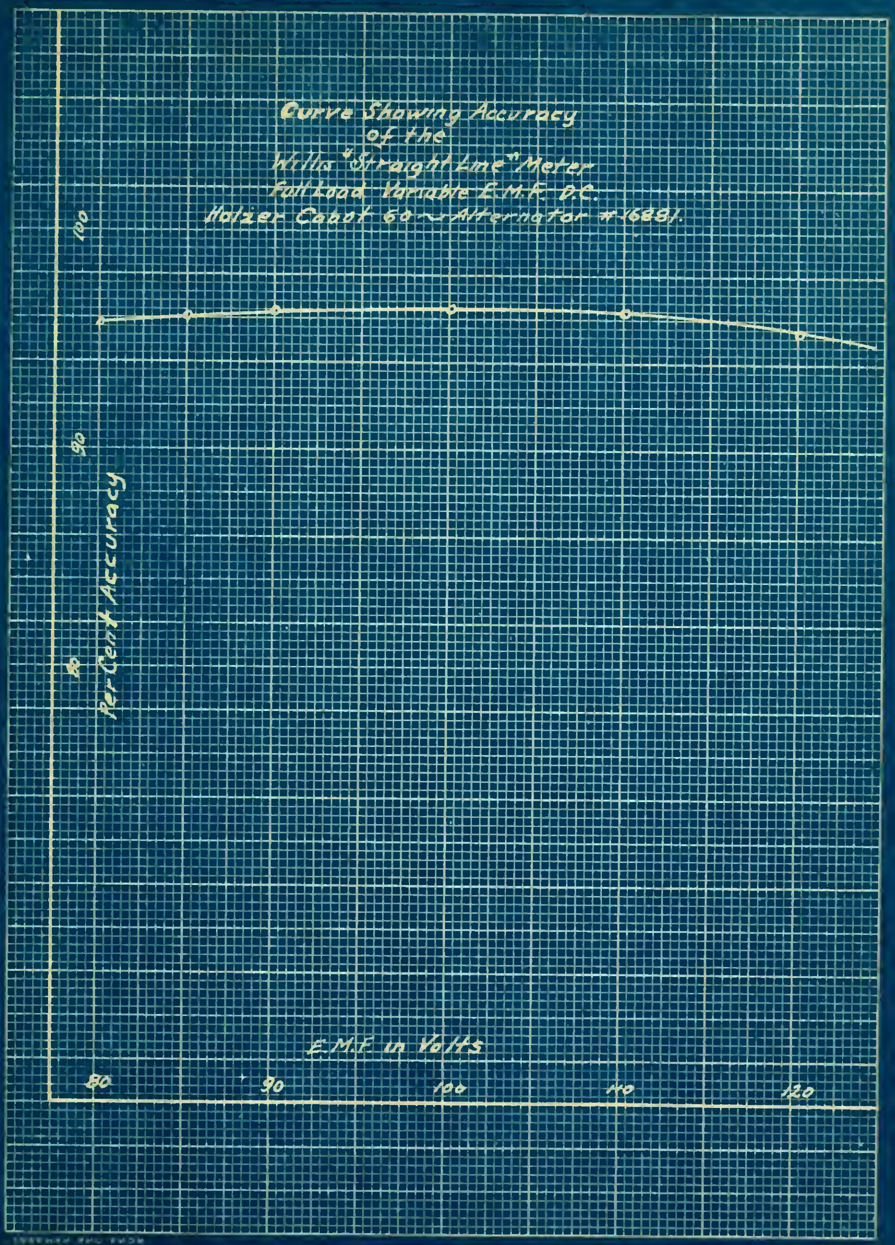
Data showing the effect of varying the pressure from 80 to 120 volts at full load when the meter was supplied with alternating current from the Holzer Cabot 60 cycle alternator # 16881.

Unity power factor.

Temperature 23.0 --- 23.5 C.

Duration of each run six minutes.

Volts.	Rev.	True W.H.	Meter W.H.	% Accuracy.
79.7	459	40.0	38.3	95.8
89.8	523	45.2	43.5	96.2
99.9	579	50.0	48.3	96.6
110.0	646	55.7	53.8	96.3
120.0	690	60.3	57.5	95.3



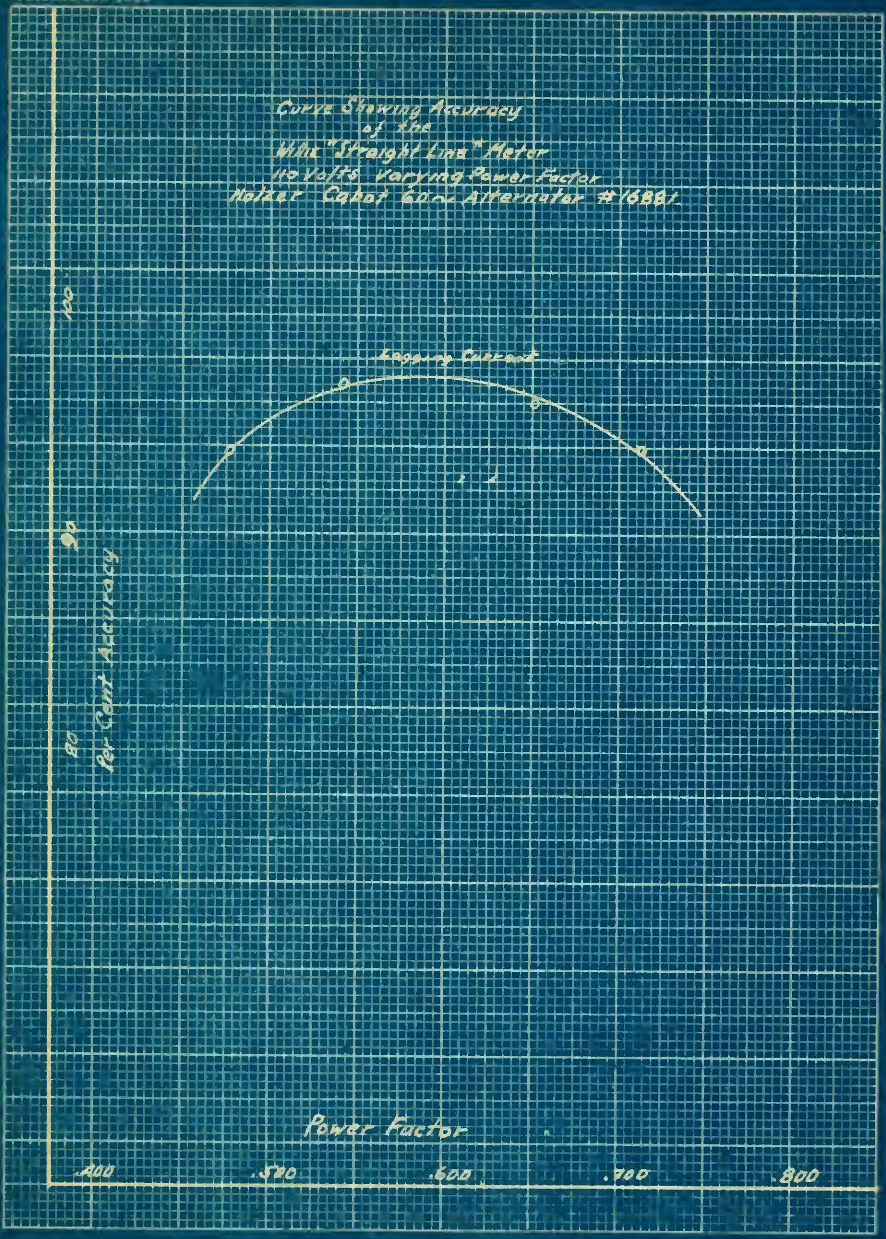
Curve Showing Accuracy
of the
Willis "Straight Line" Meter
Full Load Variable E.M.F. D.C.
Holzer Cabot 60 ~ Alternator #16881.

Data showing the effect of varying the power factor (lagging current) at 110 volts and varying load when the meter was supplied with alternating current from the Holzer Cabot 60 cycle alternator # 16881.

Temperature 23.3 --- 23.8 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.22	.475	131	11.6	10.9	93.8
4.39	.538	304	26.0	25.2	97.0
6.50	.652	537	46.6	44.7	95.9
7.77	.743	718	63.4	59.8	94.1

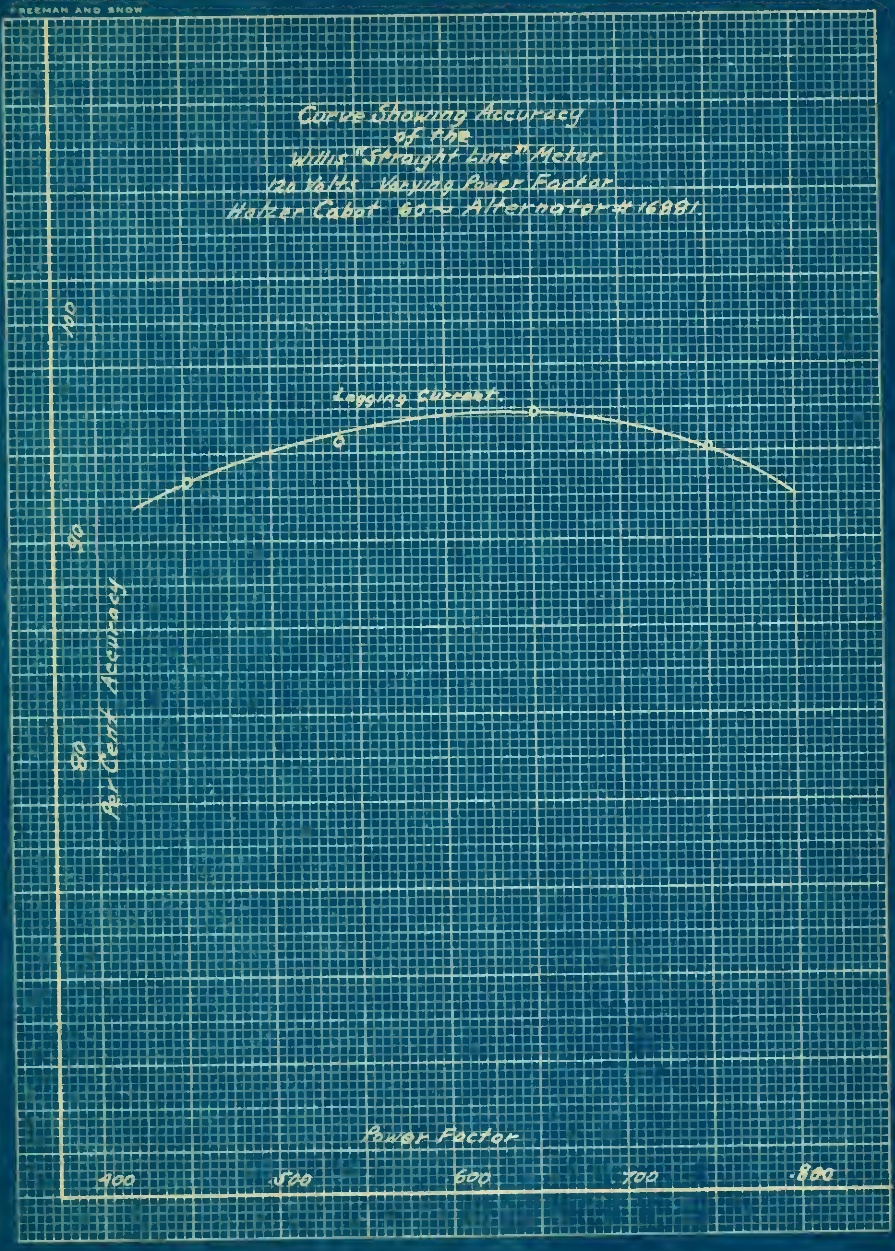

Curve Showing Accuracy
of the
Wilms "Straight Line" Meter
110 Volts Varying Power Factor
Holtzer Cabot 60~ Alternator #16881

Data showing the effect of varying the power factor (lagging current) at 120 volts and varying load when the meter was supplied with alternating current from the Holzer Cabot 60 cycle alternator # 16881.

Temperature 23.6 ---24.0 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.00	.450	120	10.8	10.0	92.6
4.45	.540	329	28.9	27.4	94.7
6.50	.655	588	51.2	49.2	96.0
7.80	.750	796	70.3	66.3	94.2



Curve Showing Accuracy
of the
Willis "Straight Line" Meter
120 Volts Varying Power Factor
Holtzer Cabot 60~ Alternator # 16881.

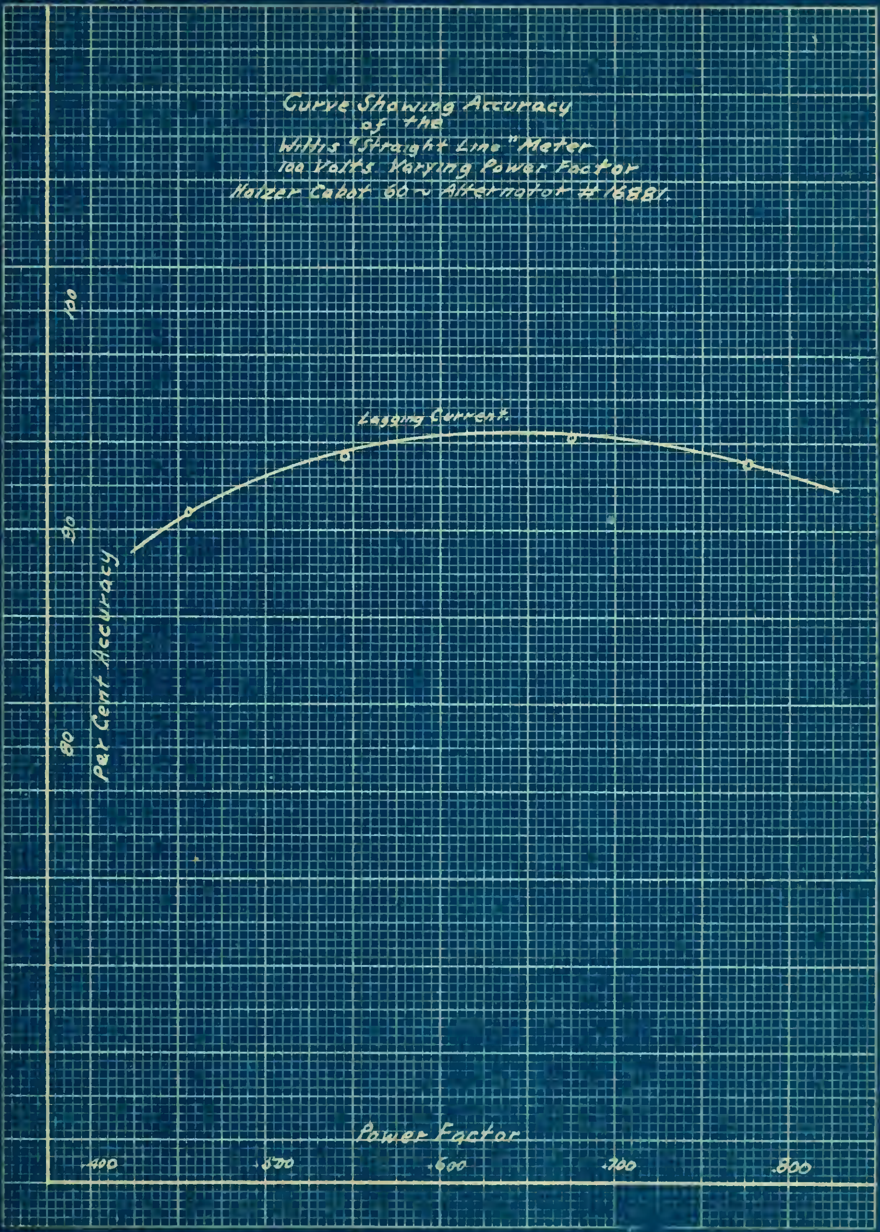
Data showing the effect of varying the power factor (lagging current) at 100 volts and varying load when the meter was supplied with alternating current from the Holzer Cabot 60 cycle alternator # 16881.

Temperature 23.8 --- 24.4 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.06	.455	102	9.37	8.51	90.8
4.49	.544	286	24.9	23.4	93.5
6.62	.676	510	44.9	42.5	94.4
7.93	.773	687	61.4	57.3	93.2

FREEMAN AND SNOW



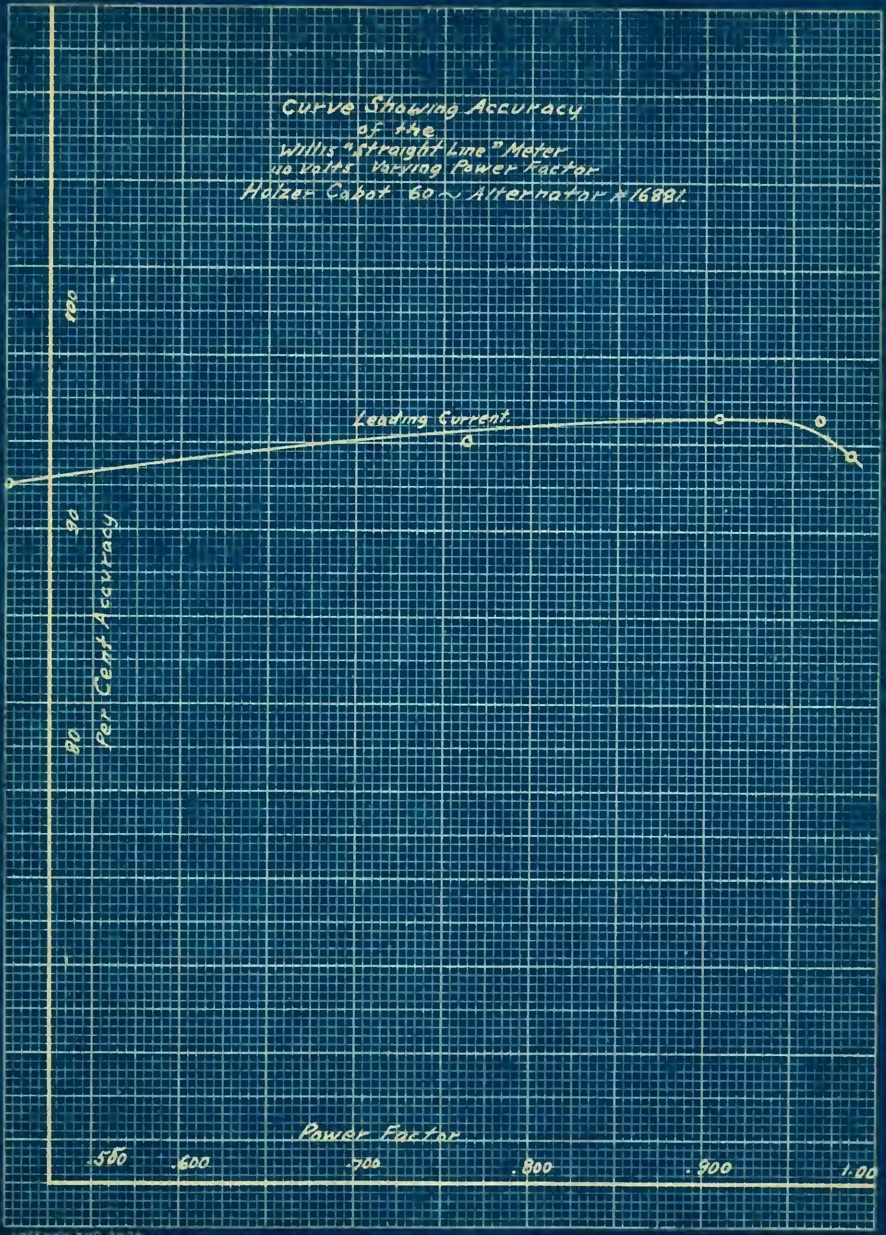
Curve Showing Accuracy
of the
Willis "Straight Line" Meter
100 Volts Varying Power Factor
Holzer Cabot 60 ~ Alternotor # 16881.

Data showing the effect of varying the power factor (leading current) at 110 volts and varying load when the meter was supplied with alternating current from the Holzer Cabot 60 cycle alternator # 16881.

Temperature 24.0 --- 24.8 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.00	.500	121	11.0	10.1	92.0
3.10	.764	298	26.4	24.8	94.2
4.30	.907	490	42.9	40.8	95.1
7.07	.964	852	74.8	71.0	95.0
7.69	.973	921	82.2	76.6	93.1



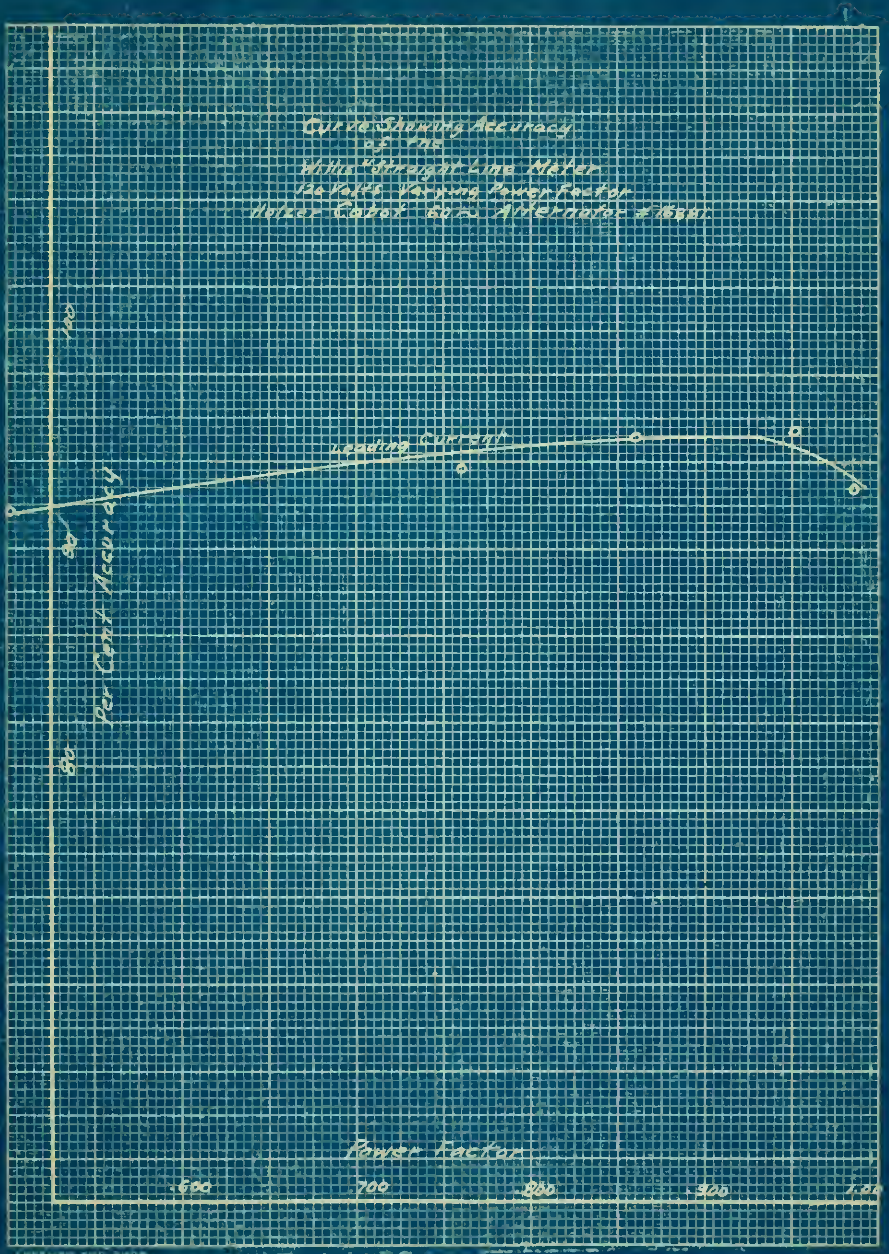
Curve Showing Accuracy
of the
Willis "Straight Line" Meter
110 Volts Varying Power Factor
Holzer Cabot 60 ~ Alternator # 16881.

Data showing the effect of varying the power factor (leading current) at 120 volts and varying load when the meter was supplied with alternating current from the Holzer Cabot 60 cycle alternator # 16881.

Temperature 24.5 --- 25.0 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.00	.498	132	12.00	11.0	91.7
3.04	.758	313	27.80	26.1	93.8
4.42	.916	557	48.70	46.4	95.2
6.50	.954	857	74.70	71.3	95.6
8.05	.985	1057	95.20	88.0	92.3

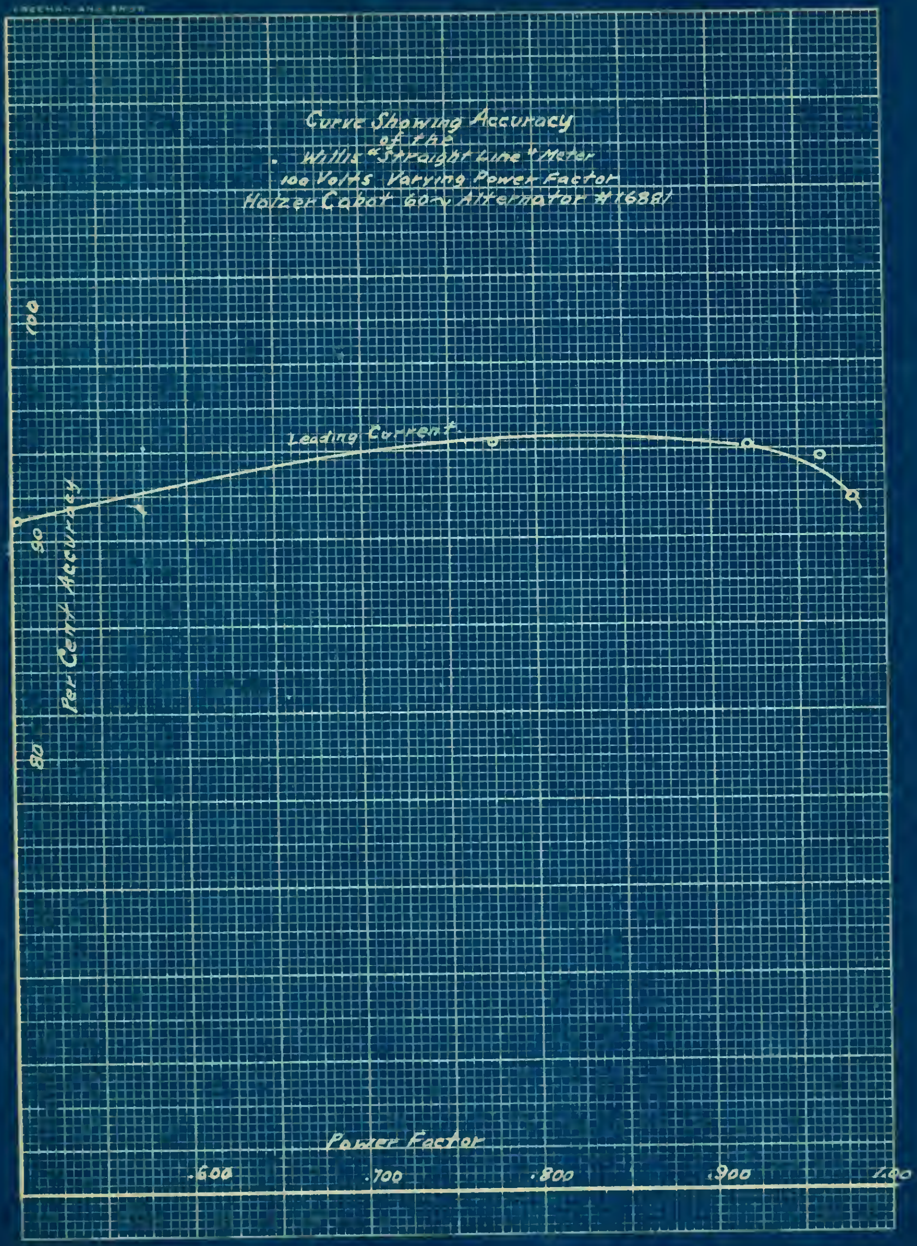

Curve Showing Accuracy
of the
Willis "Straight Line Meter
120 Volts Varying Power Factor
Holzer Cabot 60~ Alternator #16881.
Leading Current
Per Cent Accuracy
100
90
80
Power Factor
.600
700
800
900
1.0

Data showing the effect of varying the power factor (leading current) at 100 volts and varying load when the meter was supplied with alternating current from the Holzer Cabot 6 0 cycle alternator # 16881.

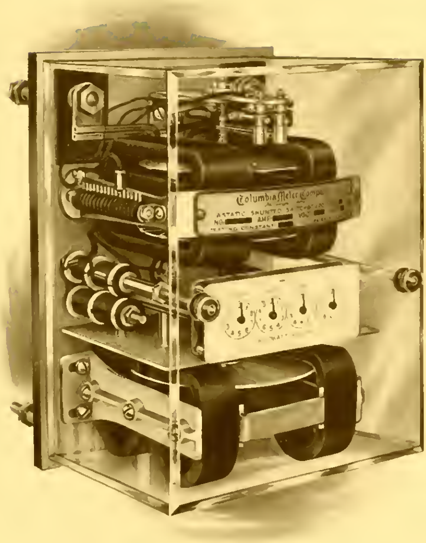
Temperature 24.8 --- 25.3 C.

Duration of each run six minutes.

Amp.	P.F.	Rev.	True W.H.	Meter W.H.	% Accuracy.
2.04	.503	112	10.3	9.33	90.8
3.26	.776	288	25.4	24.0	94.5
4.52	.922	469	41.6	39.1	94.0
6.60	.957	712	63.2	59.2	93.7
7.81	.982	848	76.8	70.6	91.8



Curve Showing Accuracy
of the
Willis "Straight Line" Meter
100 Volts Varying Power Factor
Holzer Cabot 60~ Alternator #16881



STANDARD MODEL
SWITCHBOARD METER, TYPE "S.A."

The Columbia Shunted Astatic Integrating Wattmeter, photographs of which are shown on the following pages, is best suited for operation on direct current. The meter is 10 1/4" by 7" and is 6 7/16" deep. It is covered by a metal case, which has a glass panel thru which we may read the kilowatt hours consumed by the meter. The dials are at the central part of the meter.

The armature of this meter differs from the usual type of armature and is constructed as follows. The shaft has two thin aluminum discs near the top and the third disc at the bottom which acts as a brake. Between the two upper discs are placed six cylindrical spools equally placed near the central shaft. Thru each spool is a thin strip of silicon steel with its ends bent at right angles so as to extend radially along the lower surface of the upper disc.and the upper surface of the lower disc. These radial extensions are split so as to divide the flux more evenly around the disc circumference. The six spools carry the winding of the armature.

The current circuit consists of four coils, two on the upper disc and two on the lower disc. They are connected in such a way that the field of one is opposed to the other. Now if a stray field acts on one coil so as to weaken it, it will cause the other coil to be strenghened an equal amount thereby neutralizing the effect.

The lower bearings are of the cup shaped diamond, and are very easily removed in case of a defect.

The meter is also equipped with compensating coils which can be plugged in or out to adjust for light loads. Standard shunts are provided with the meter.different gear ratios being used for each.

All tests on the Columbia Shunted Astatic Meter #18600 were made with direct current. The scheme of connections is shown on the following page. Current was obtained from a single storage cell and the supply of current was regulated by means of a carbon plate rheostat. The pressure was obtained from a storage battery situated in the north laboratory and the voltage was maintained constant by means of a variable potential rheostat.

The following tests were made:

1. Meter operated at 110 volts with load varying from 0 to 50% overload .

2. Meter operated at 120 volts with load varying from 0 to 50% overload.

3. Meter operated at 100 volts with load varying from 0 to 50% overload.

4. Meter operated at full load with variable e.m.f.

5. Meter operated at 80% of full load with variable e.m.f.

6. Meter operated at 120% of full load with variable e.m.f.

7. Meter operated at 110 volts and full load with variations in compensating coil.

8. Meter operated at 110 volts and 40% of full load with variations in compensating coil.

9. Meter operated at 110 volts and 150% of full load with variations in compensating coil.

10. Meter operated at 110 volts with load varying from 0 to 50% overload when the meter was placed in a strong magnetic field.

11. Temperature tests.

12. Meter tested with a standard shunt of .001 ohm.

For each run the time required for the disc to make 150 revolutions was noted and the current and the voltage were recorded.

For test number ten a strong electromagnet was placed eight inches from the meter, first on one side of it, then on the other.

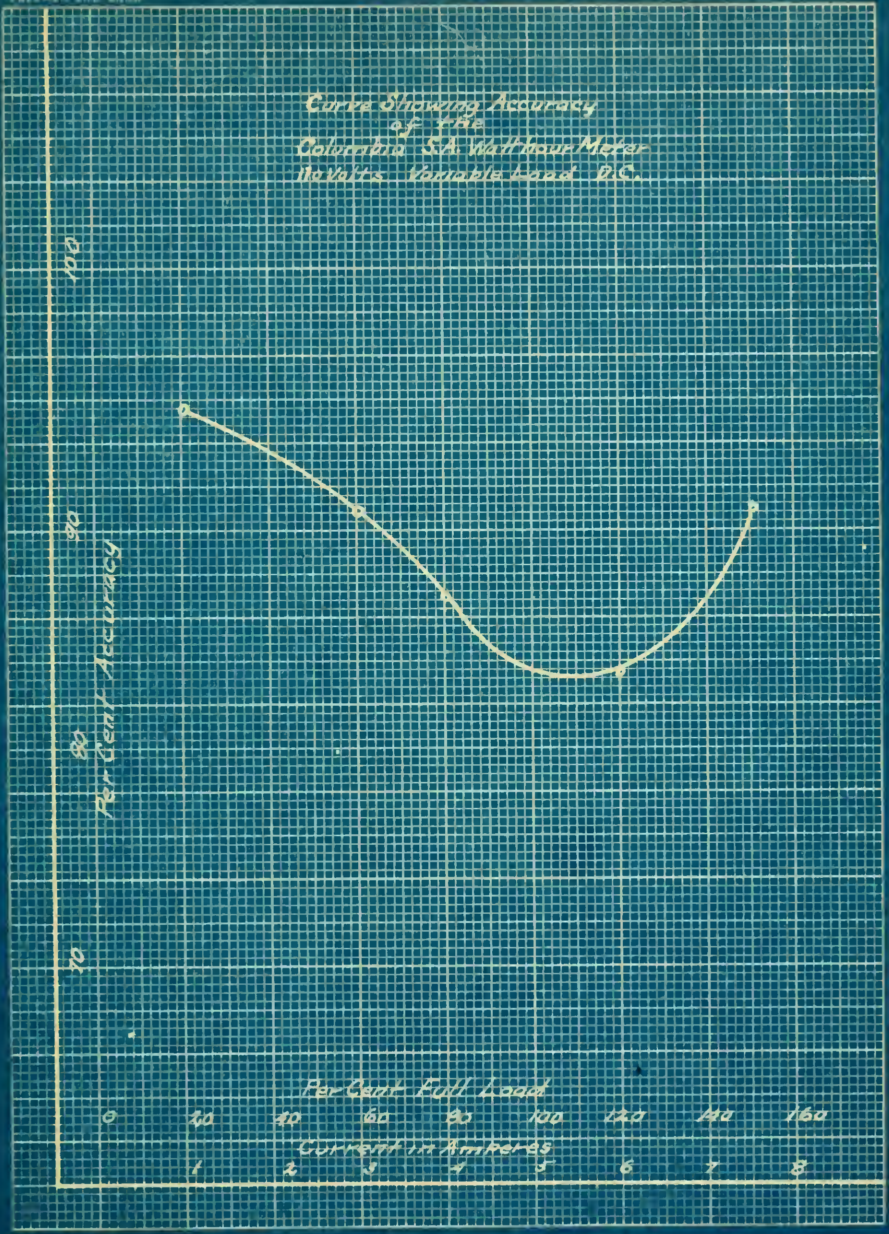
For test number eleven the meter was placed in a large air- tight box containing four electric heaters, which were used to vary the temperature of the meter. Runs were made for four variations in temperature.

For test number twelve the current coil of the meter was shunted across a standard resistance of .001 ohm. This resistance carried the major portion of the current.

Data showing the effect of varying the load from 0 to 50% overload when the meter was operated at 110 volts.

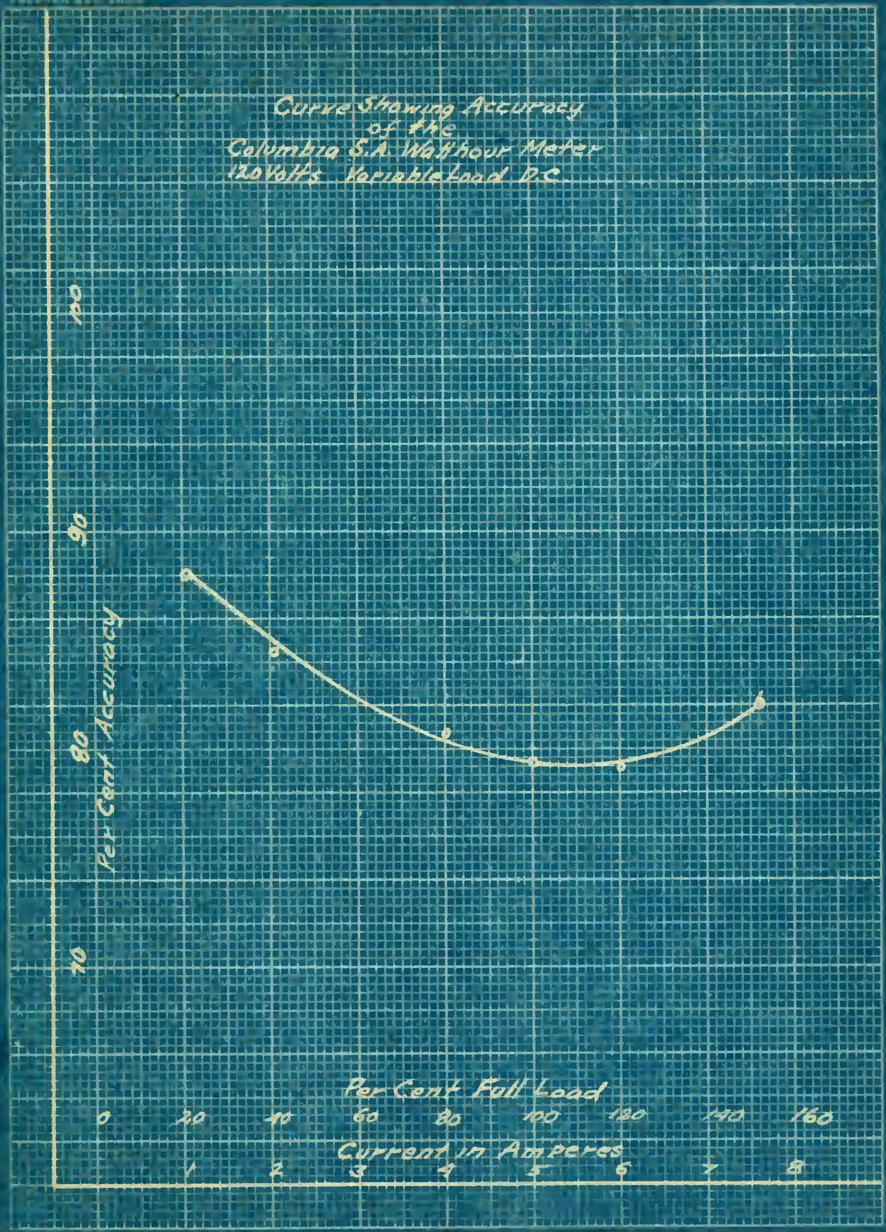
Amperes.	Time in sec.	True W.H.	Meter W.H.	% Accuracy.
.94	1380	39.6	37.5	95.5
1.95	690	41.2	37.5	91.0
2.97	458	41.5	37.5	90.3
4.00	355	43.4	37.5	86.4
5.03	280	43.1	37.5	86.8
6.08	240	45.2	37.5	82.8
7.60	177	41.2	37.5	91.0

FREEMAN AND SNOW



Data showing the effect of varying the load from 0 to 50% overload when the meter was operated at 120 volts.

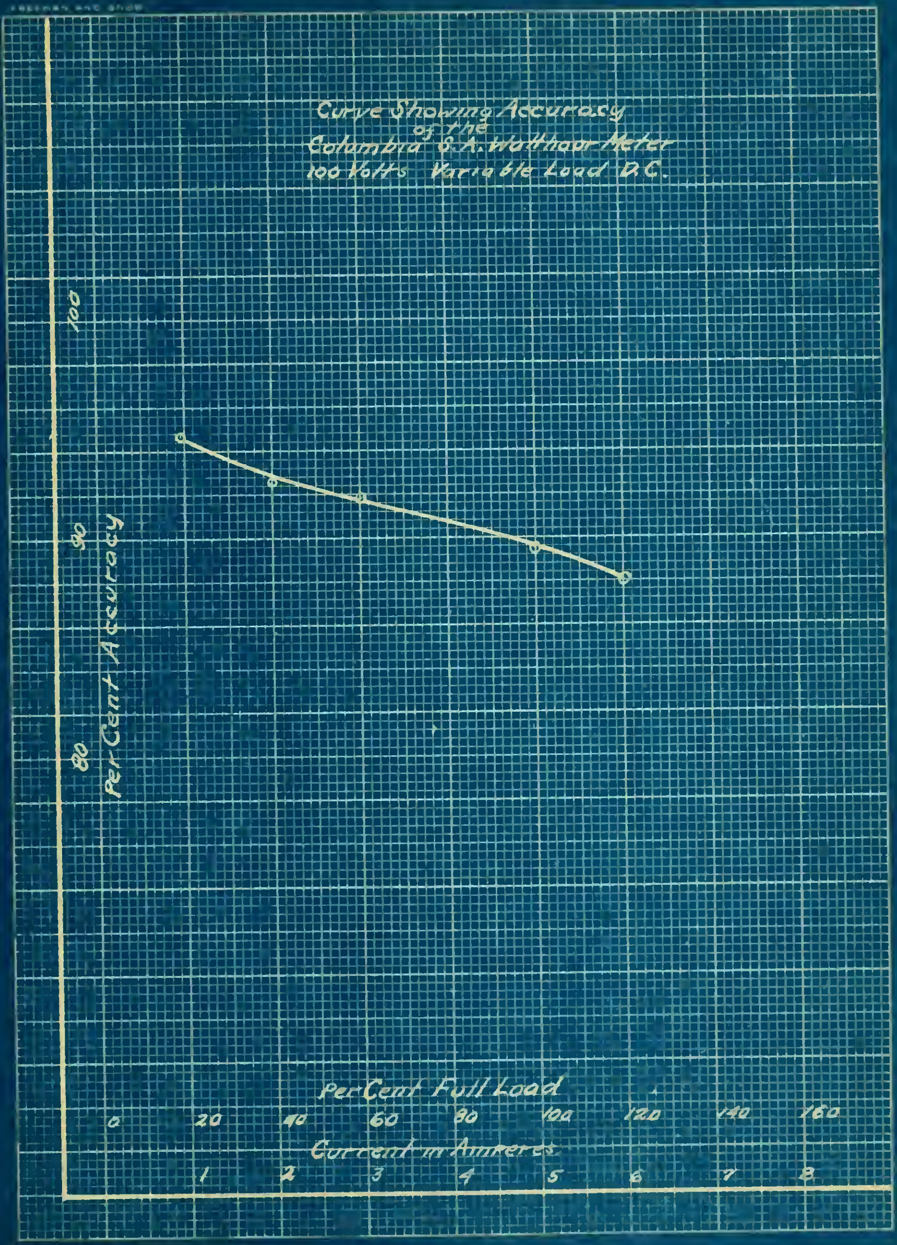
Amperes.	Time in sec.	True W.H.	Meter W.H.	% Accuracy
.94	1365	42.6	3.75	88
1.95	690	44.9	3.75	83.7
2.97	492	48.7	3.75	77
4.00	340	45.4	3.75	82.4
5.03	280	46.9	3.75	80
6.08	228	46.4	3.75	80.5
7.60	180	45.6	3.75	82



Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
120 Volts Variable Load D.C.

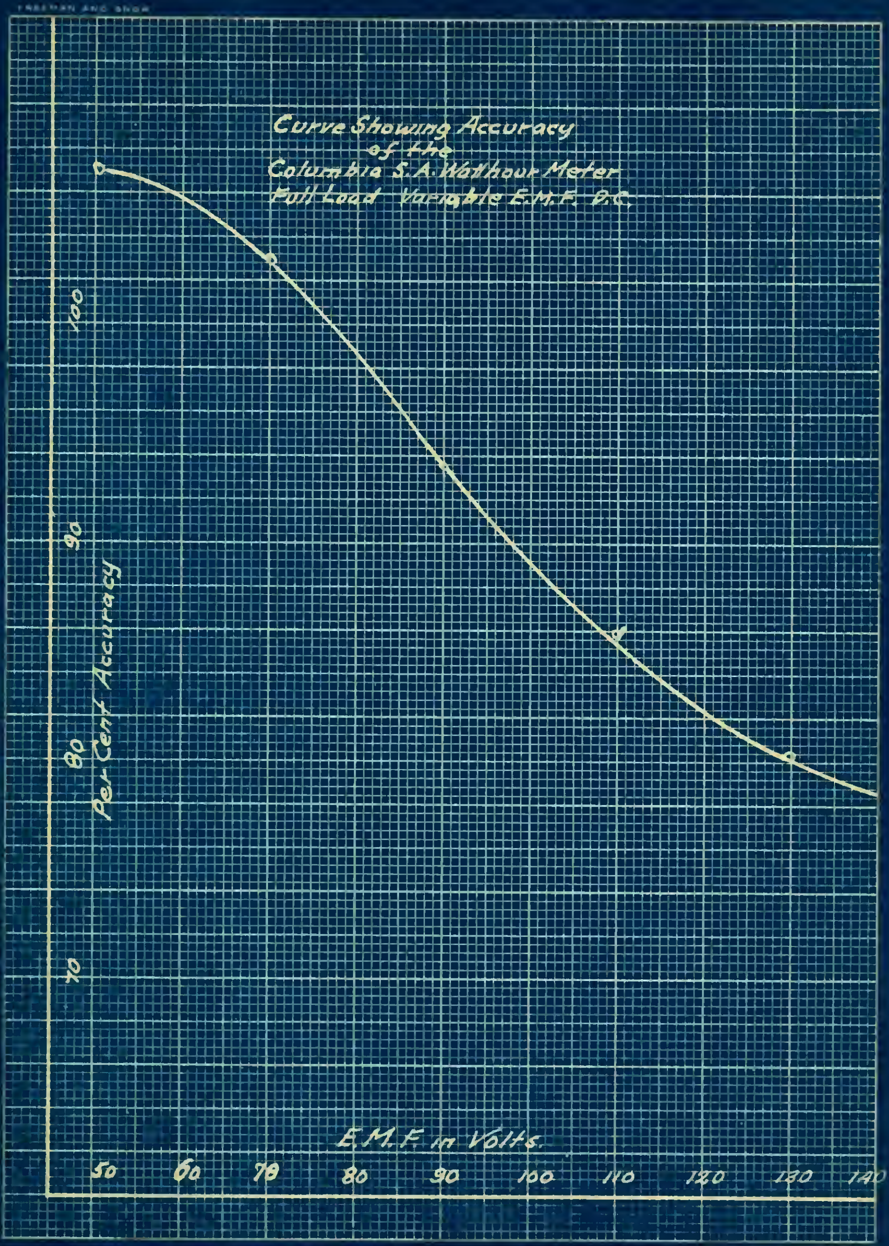
Data showing the effect of varying the load from 0 to 50% overload when the meter was operated at 100 volts.

Amperes.	Time in sec.	True W.H.	Meter W.H.	% Accuracy
.94	1530	40.0	37.5	94.7
1.95	750	40.6	37.5	92.4
2.97	495	40.8	37.5	91.8
4.00	390	43.3	37.5	86.5
5.03	300	42.0	37.5	89.4
6.08	252	42.6	37.5	88.0
7.60	192	40.6	37.5	92.4


Curve Showing Accuracy
of the
Columbia O.A. Watthour Meter
100 Volts Variable Load D.C.
100
90
80
Per Cent Accuracy
Per Cent Full Load
0
20
40
60
80
100
120
140
160
Current in Amperes
1
2
3
4
5
6
7
8

Data showing the effect of varying the pressure at full load.

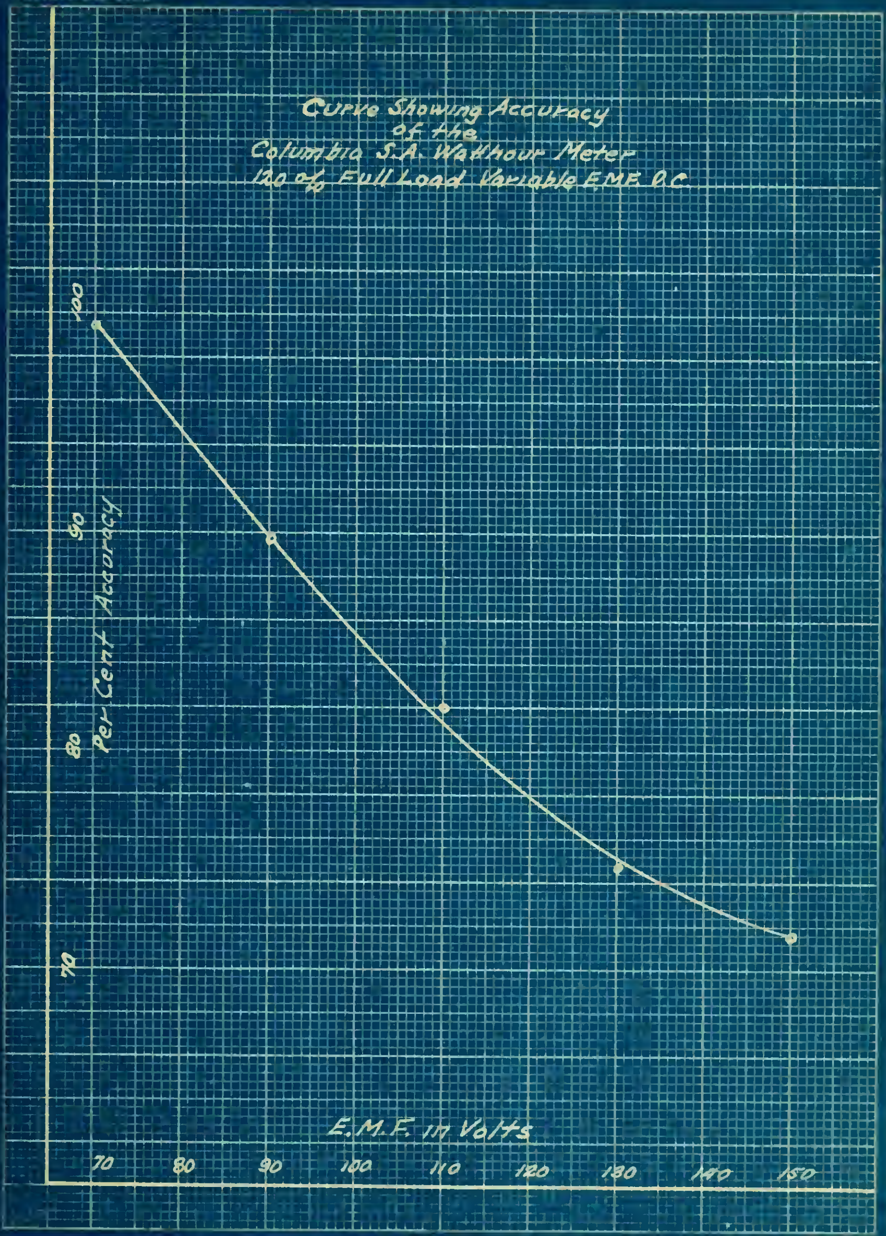
Volts.	Time in sec.	True W.H.	Meter W.H.	% Accuracy
50.6	495	35.0	37.5	107.0
70.3	370	36.4	37.5	103.0
90.2	320	40.3	37.5	93.0
110.0	280	43.1	37.5	86.8
129.9	258	46.6	37.5	80.2
149.7	249	52.0	37.5	72.0



Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
Full Load Variable E.M.F. D.C.

Data showing the effect of varying the pressure at 120% of full load.

Volts.	Time in sec.	True W.H.	Meter W.H.	% Accuracy.
70.3	330	37.6	37.5	99.4
90.2	280	42.2	37.5	88.6
110.0	240	44.0	37.5	85.0
129.9	230	49.8	37.5	75.3
149.7	210	52.4	37.5	71.4

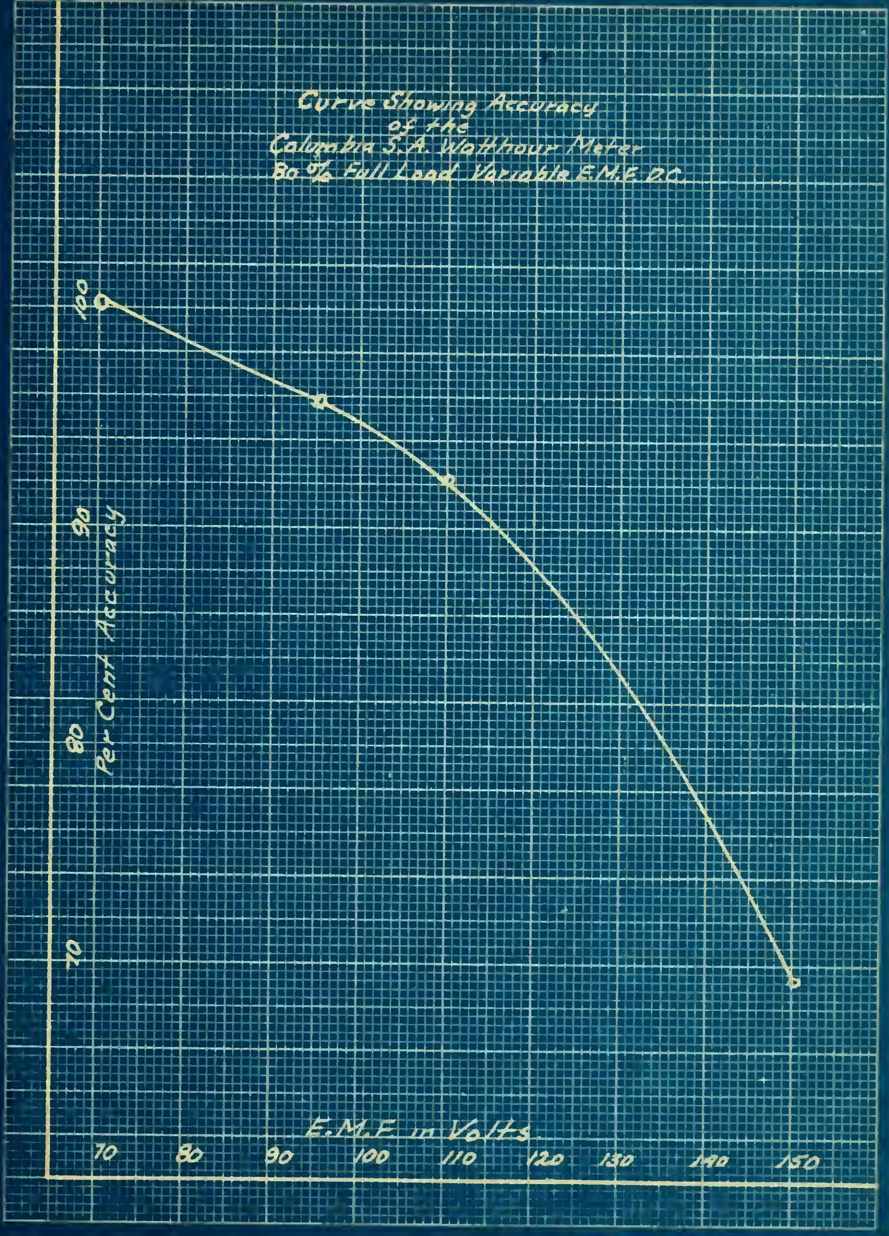


Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
120 % Full Load Variable E.M.F. D.C

Data showing the effect of varying the pressure at 80% of full load.

Volts.	Time in sec.	True W.H.	Meter W.H.	% Accuracy
70.3	480	37.4	37.5	100.1
90.2	390	39.1	37.5	95.8
110.0	355	43.0	37.5	92.2
129.9	330	47.4	37.5	78.9
149.7	325	54.0	37.5	69.3

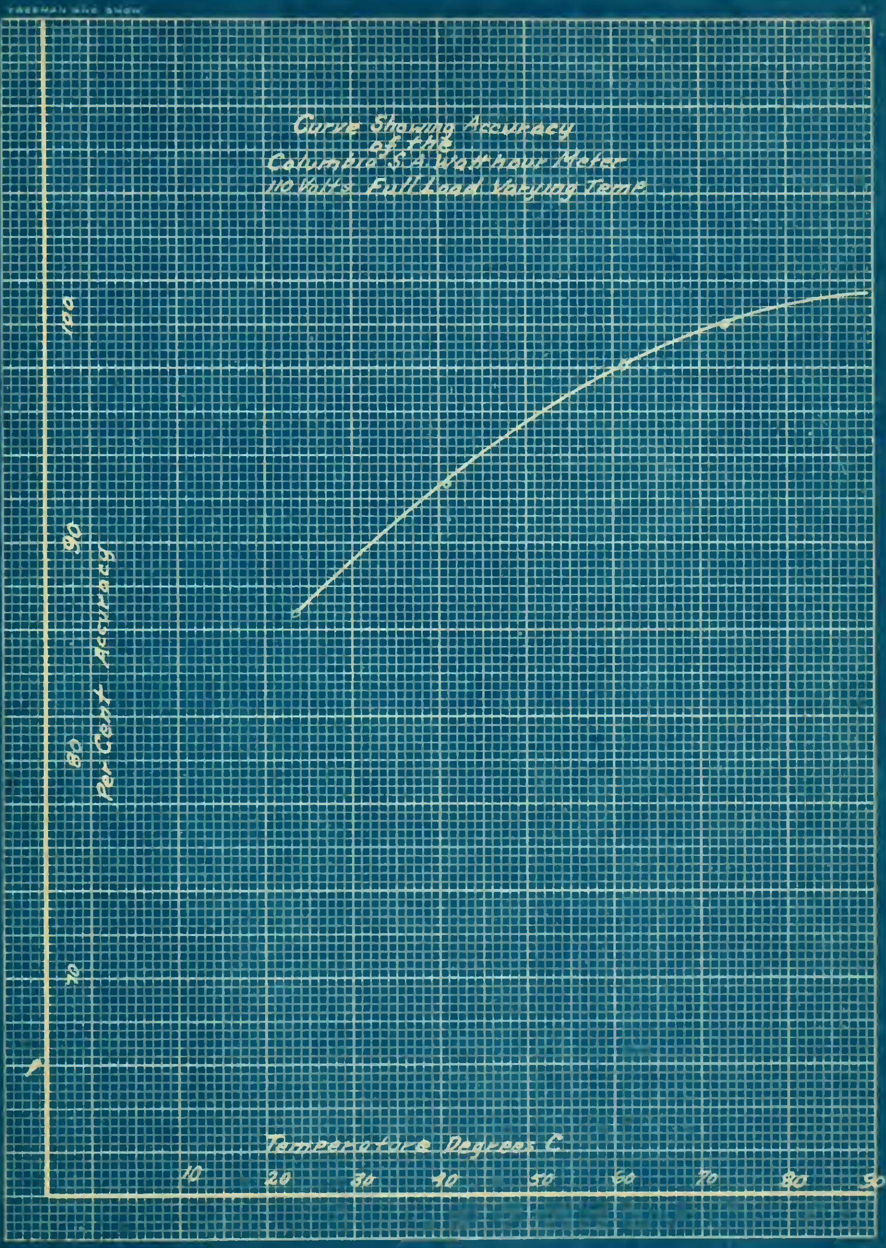
FREEMAN AND SHAW



Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
80 % Full Load Variable E.M.F. D.C.

Data showing the effect of varying the temperature at 110 volts and full load.

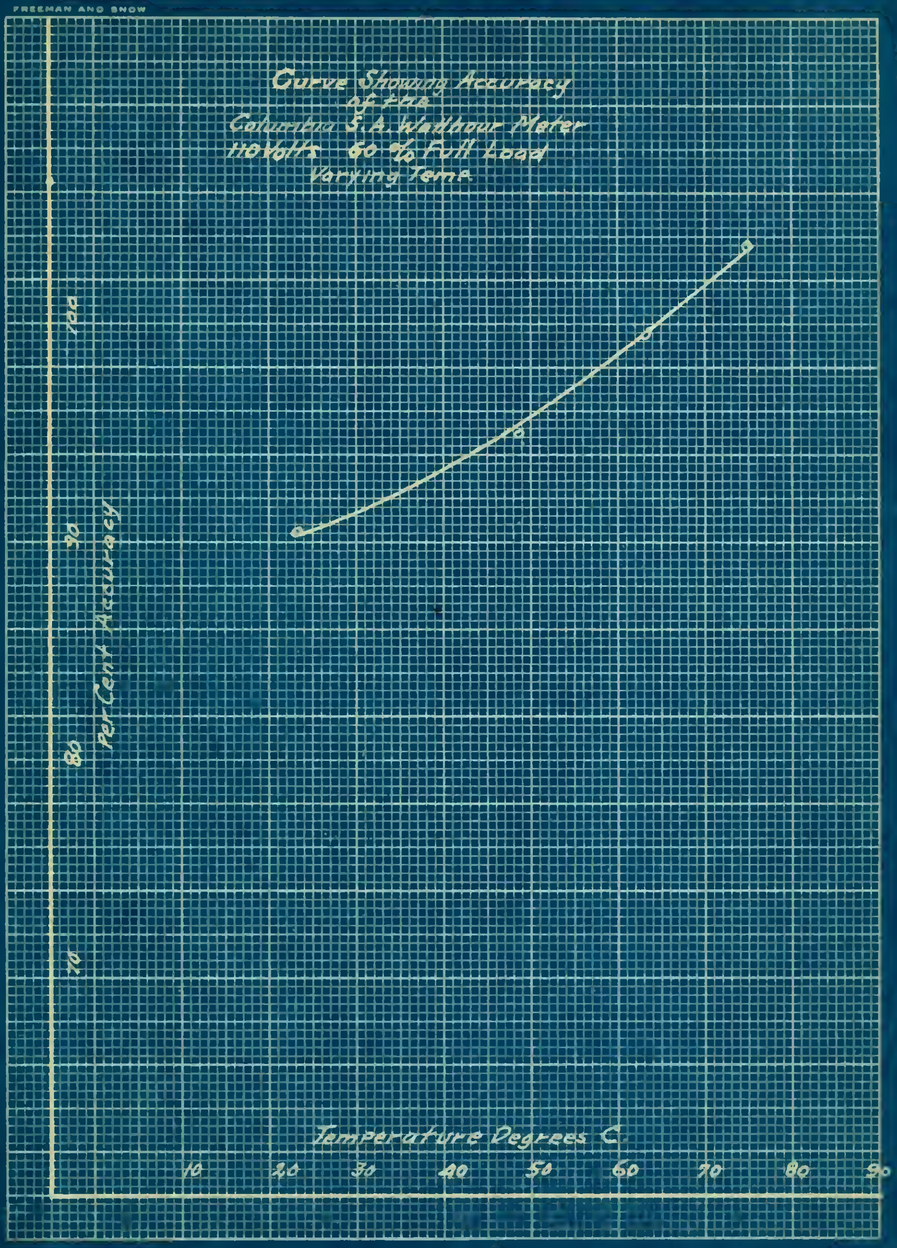
Temp.	Time in sec.	True W.H.	Meter W.H.	% Accuracy.
23	280	43.1	37.5	86.8
41	268	41.2	37.5	91.0
61	249	38.2	37.5	98.2
73	243	37.4	37.5	100.2



Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
110 Volts Full Load Varying Temp.

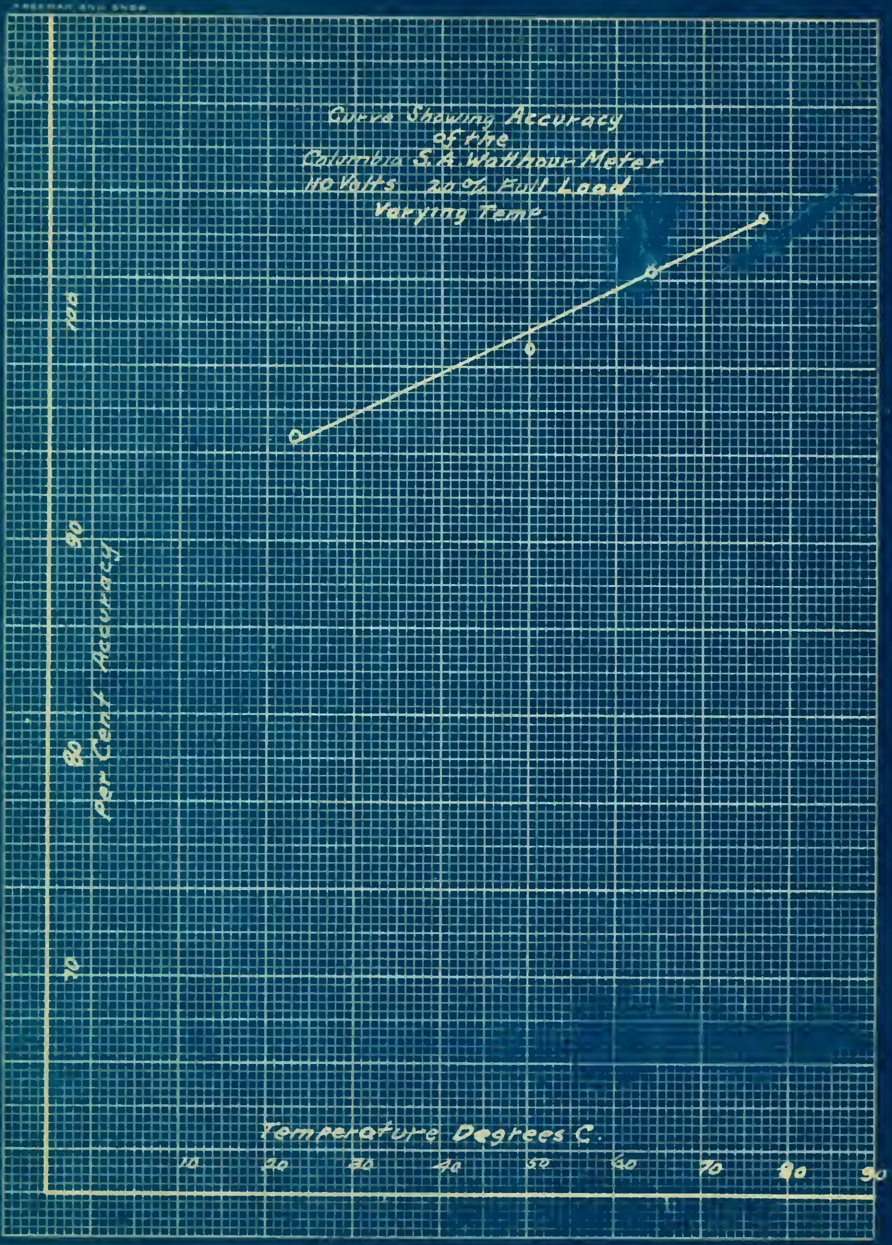
Data showing the effect of varying the temperature at 110 volts and 60% of full load.

Temp.	Time in sec.	True W.H.	Meter W.H.	% Accuracy
23	458	41.5	37.5	90.3
48	432	39.2	37.5	95.5
62	414	37.5	37.5	100.0
75	399	36.2	37.5	103.5


FREEMAN AND SNOW
Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
110 Volts 60 % Full Load
Varying Temp.
Per Cent Accuracy
100
90
80
70
Temperature Degrees C.
10
20
30
40
50
60
70
80
90

Data showing the effect of varying the temperature at 110 volts and 20% of full load.

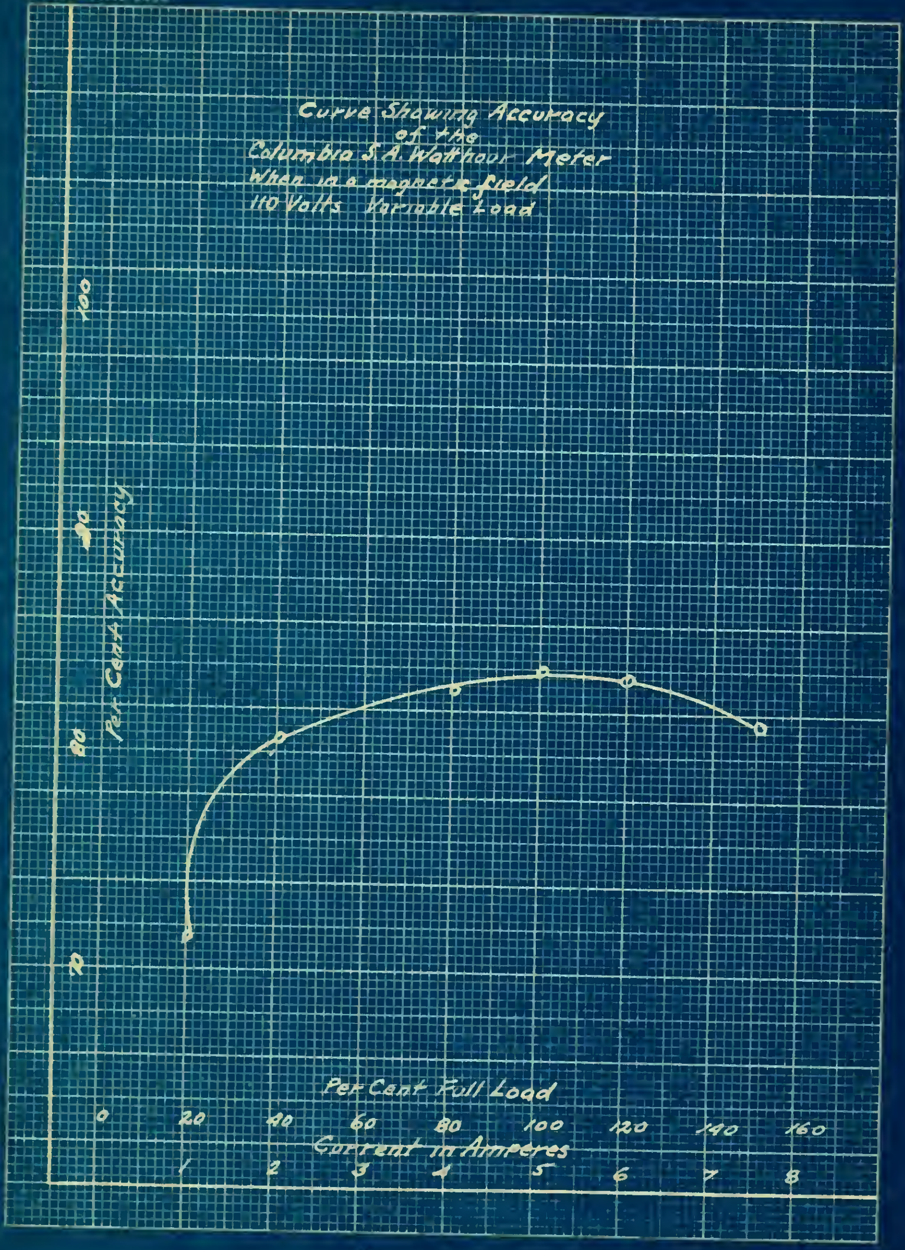
Temp.	Time in sec.	True W.H.	Meter W.H.	%Accuracy.
23	1380	39.6	37.5	95.5
50	1320	37.9	37.5	98.7
64	1275	36.6	37.5	102.4
77	1242	35.7	37.5	104.9


FREEMAN AND SNOW
Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
110 Volts 20% Full Load
Varying Temp.
100
90
80
70
Per Cent Accuracy
Temperature Degrees C.
10
20
30
40
50
60
70
80
90

Data showing the effect of a magnetic field when produced to the right of the meter, voltage 110.

Amperes.	Time in sec.	True W.H.	Meter W.H.	%Accuracy.
.94	1830	52.5	37.5	71.5
1.95	780	46.4	37.5	80.7
2.97	495	44.8	37.5	83.7
4.00	370	45.2	37.5	82 .8
5.03	290	44.6	37.5	83.8
6.08	240	44.7	37.5	83.6
7.60	198	46.1	37.5	81.4

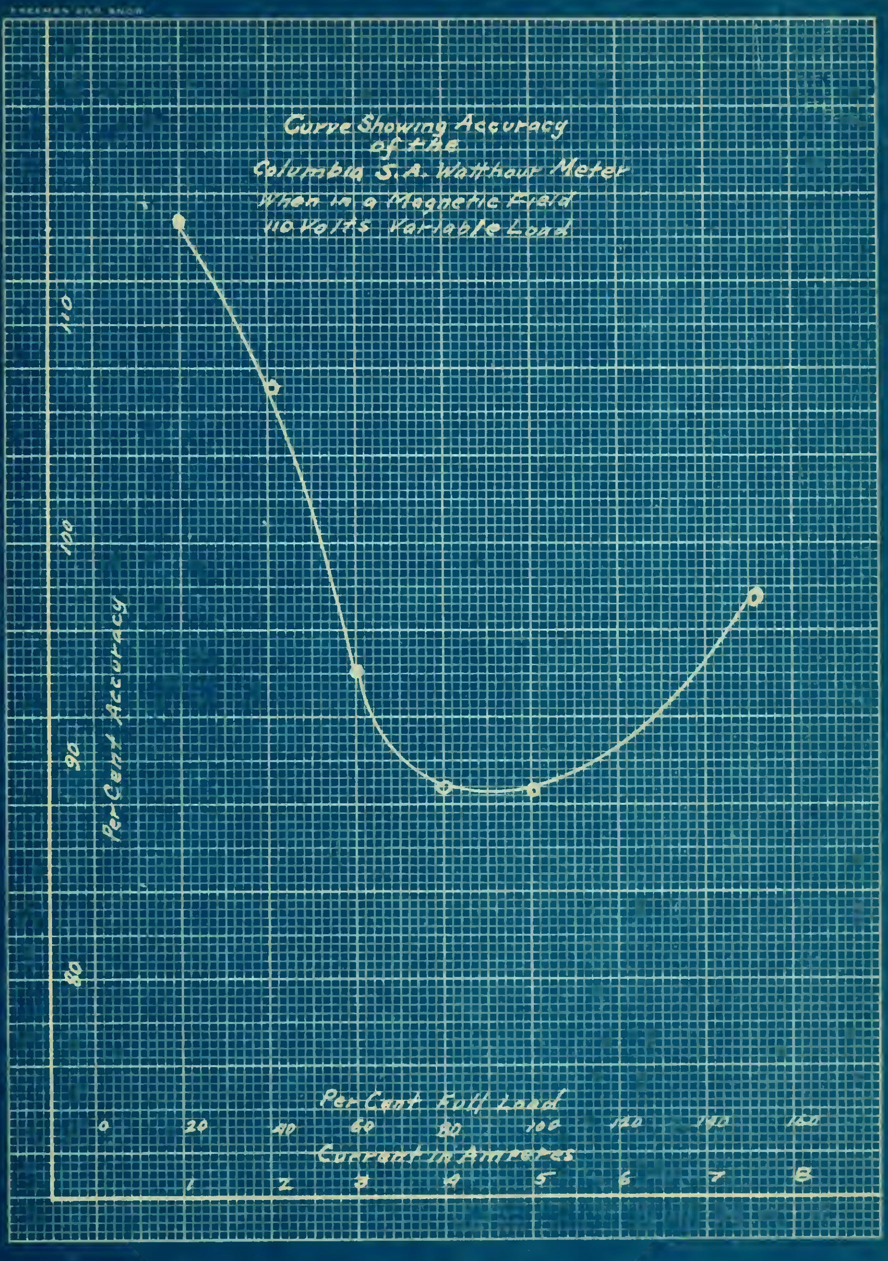
FREEMAN AND SNOW



Curve Showing Accuracy
of the
Columbia S. A. Watthour Meter
When in a magnetic field
110 Volts Variable Load

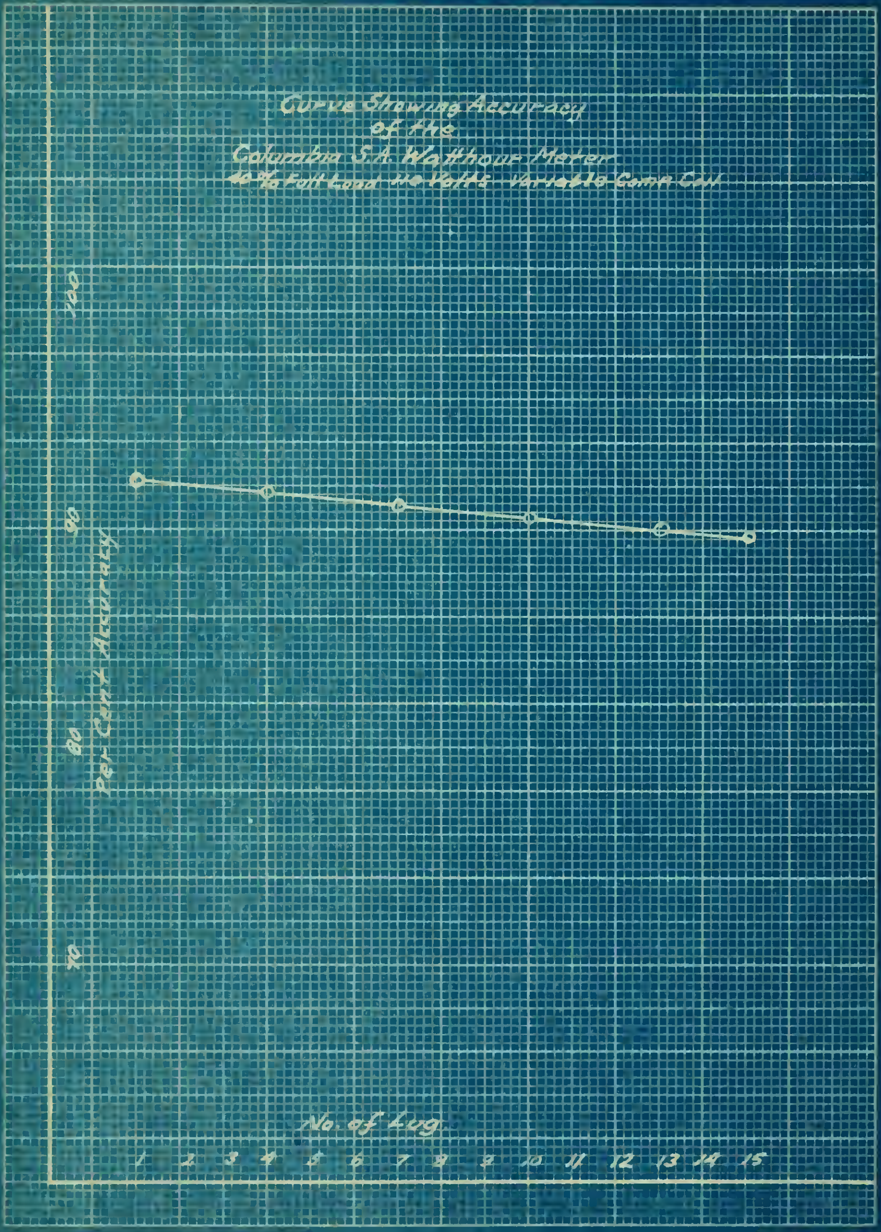
Data showing the effect of a magnetic field when produced to the left of the meter, voltage 110.

Amperes	Time in sec.	True W.H.	Meter W.H.	% Accuracy
.94	1140	32.6	37.5	114.7
1.95	630	37.5	37.5	100.0
2.97	435	39.6	37.5	94.8
4.00	345	42.2	37.5	88.7
5.03	275	42.3	37.5	88.5
6.08	237	40.0	37.5	93.7
7.60	165	38.5	37.5	97.0

FREEMAN AND SNOW
Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
When in a Magnetic Field
110 Volts Variable Load
Per Cent Accuracy
110
100
90
80
Per Cent Full Load
0
20
40
60
80
100
120
140
160
Current in Amperes
1
2
3
4
5
6
7
8

Data showing the effect of varying the compensating coil at 110 volts and 40% of full load.

No. of lug.	Time in sec.	True W.H.	Meter W.H.	%Accuracy
1	683	40.7	37.5	92.2
7	690	41.1	37.5	91.2
15	704	42.2	37.5	88.9

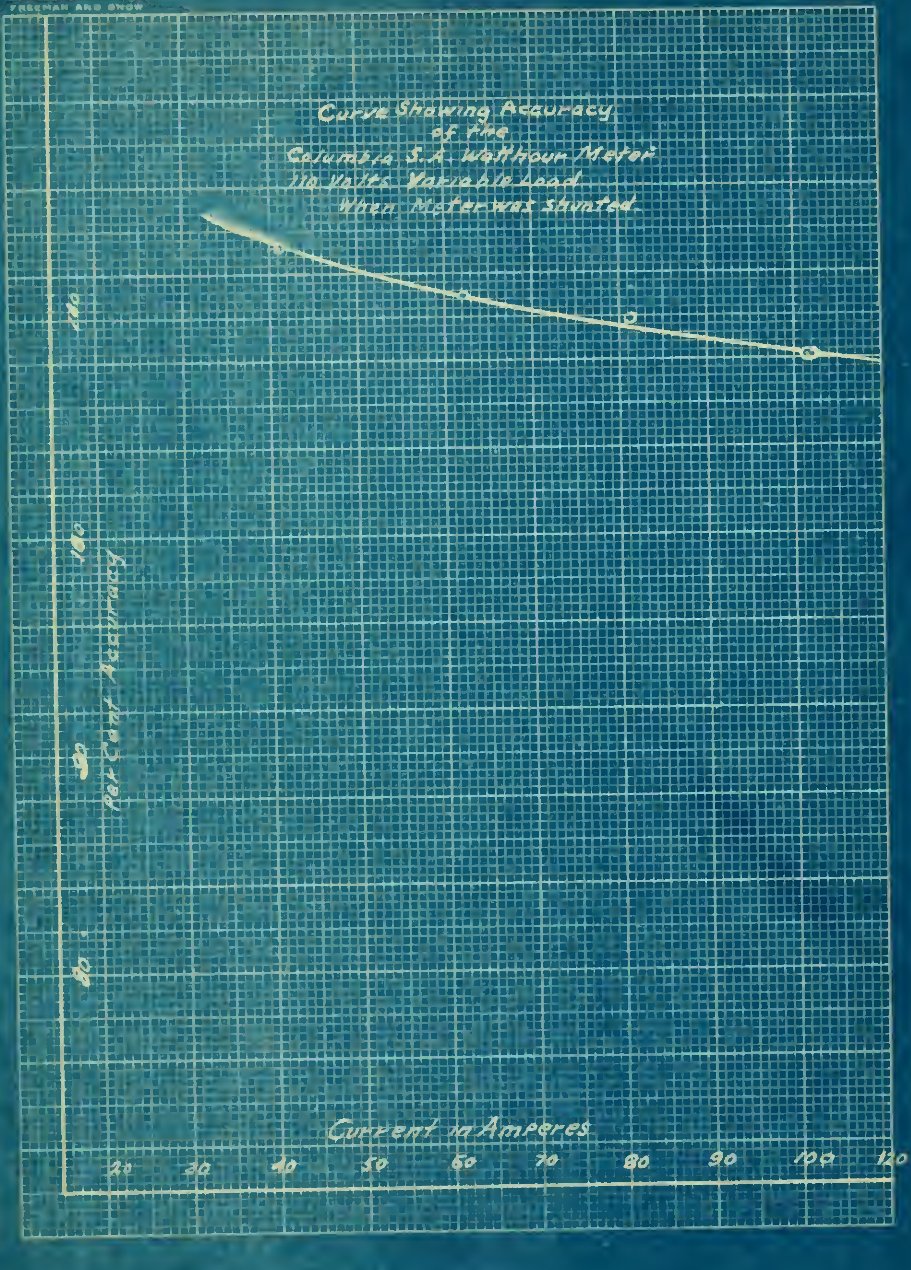


Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
40% Full Load 110 Volts Variable Comp Coil

Data showing the effect of shunting the current thru a .001 ohm standard resistance when the e.m.f. was 110 volts.

Amperes.	Time in sec.	True W.H.	Meter W.H.	%Accuracy.
20.7	1086	688	750	108.8
41.4	522	662	750	113.2
62.1	354	674	750	111.4
82.3	268	675	750	111.2
103.0	219	690	750	108.8
124.8	183	700	750	107.2

FREEMAN AND SNOW


Curve Showing Accuracy
of the
Columbia S.A. Watthour Meter
110 Volts Variable Load
When Meter was Shunted

Discussion

In discussing the tests we have just completed we will take each meter separately. First we will discuss the Willis "Straight Line" Meter D. C. tests.

Test #1. 110 volts variable load. This test showed that the percent of accuracy was a little high at low loads and low at high loads.

Test #2. 120 volts variable load. The results of this test concurred with those of test #1.

Test #3. 100 volts variable load. The results of this test were the same as the above two tests.

The three tests show that for varying voltages at any certain load the percent accuracy is about the same.

Test #4. 110 volts, full load, temperature varying from 20 to 80 degrees C. The accuracy varied from 96% at 20 degrees to 98-4/10% at 80 degrees.

Test #5. 110 volts, 60% load, varying temperature. The accuracy varying from 96-8/10% at 20 degrees to 100% at 80 degrees.

Test #6. 110 volts, 20% of full load, varying temperature. At 20 degrees the accuracy was 102-8/10%, at 50 degrees the accuracy was 114-8/10%, while at 80 degrees the accuracy dropped to 102-8/10%.

The temperature tests showed that for full load and half load, the accuracy did not vary much with change in temperature, while for low currents the accuracy varied largely with change in temperature.

Alternating current tests.

Tests #1. 110 volts, varying current, different wave shapes. These tests showed that the accuracy varied but slightly with change of wave shape.

Tests #2. Variable E.M.F., Unity Power Factor, Constant Loads. In these tests the accuracy decreased with high and low voltages, reaching a maximum at 105 volts.

Tests #3. 110 volts, varying power factor. lagging current. The accuracy varied from 80% at .200 power factor to 90% at .980 power factor.

Tests #4. 110 volts, 60 cycles, leading current, variable power factor. The accuracy varied from 96% at .600 power factor to 94-2/10% at .970 power factor.

Tests #5. 120 volts, varying power factor, leading current. The accuracy decreased with increase in power factor, being 96-4/10% at .67 power factor and 90-6/10% at .97 power factor.

Tests #6. 120 volts, variable power factor, lagging current. The accuracy varied with the change in power factor, the percent accuracy was 90-4/10 at .45 power factor and 92-8/10 at .77 power factor. The maximum accuracy was 94-2/10% at .65 power factor.

The alternating current tests showed as follows.

1. The accuracy depended on the power factor.
2. The accuracy varied with both lagging current and leading current, but not in the same manner.
3. The accuracy was independent of wave shape.
4. The accuracy was independent of frequency.

In the above tests an error might have been introduced owing to the vibration caused by the machines. Although the meter is adopted to alternating currents, the accuracy is very low, especially on low loads and load power factors.

The Columbia Shunted Astatic Meter

The tests were all performed on direct current. from the results obtained lead to the following conclusions.

1. The accuracy varied considerably upon change of load regardless of whether the pressure remained constant or variable.

2. The meter was effected appreciably by stray fields. In this test the effect of stray fields varied with the position and strength of the fields.

3. The temperature test show that this meter is not adapted to extreme changes in temperature.

Bibliography.

Gerhardi C. "Electricity meters".

Solomon H.G. "Electricity meters".

Columbia Shunted Astatic Switchboard Meters (Trade Catalogue.)

Federal Electric Company Bulletin #131.

Federal Electric Company Bulletin #145.